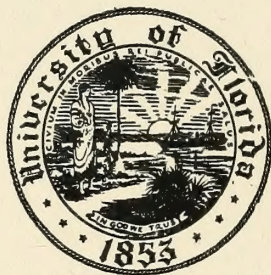


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HANDBOOK OF FOOD AND AGRICULTURE

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PREFACE

Food and agriculture constitute the largest American industry. The past decade has shown an amazing increase in research in both fields. The impact of this research on the practical, present-day development of agriculture and food has been tremendous. New mechanical equipment, new varieties of fruits and vegetables, improvements in the storage and handling of agricultural raw materials, utilization of by-products, greater attention to nutritional values of foods and feeds, improvements in storage and transportation facilities—all have contributed to the spectacular growth and present important position of these industries.

It is recognized that the field of agriculture and food is so large that it is not possible within the confines of a single volume to present, even in brief form, adequate information on all phases of all problems in both agriculture and food. Reluctantly, we have had to exclude discussions of such important fields as horticulture, agricultural engineering, genetics, plant pathology, animal breeding, climatology, and many others.

In the chapters which are included in this volume every effort has been made to bring the information on their respective subjects up to date, with additional references in each chapter to supplement, where desired, the reader's available information.

No effort has been made to present the various chapters in a uniform style. Each author has employed his own method in developing the subject matter of his chapter. Editorial changes have been kept to a minimum.

We have incorporated authoritative, hard-to-locate material from widely different sources in the appendix. We believe and hope that this supplemental material will add to the usefulness of the book and to the reader's interest.

The editor and publisher are deeply indebted to the distinguished list of collaborators whose cooperation and self-sacrifice have made possible the presentation of this volume. The editor also expresses his appreciation to the many individuals who kindly gave permission to reproduce published figures, charts, data, and photographs. These have been acknowledged in the appropriate places in the text. The development of this volume has been made possible by the vision, encouragement and advice of G. G.

Hawley, Executive Editor, Reinhold Book Division. To him the editor expresses his deep gratitude and appreciation.

We fully realize that much more material of an even wider range could well have been incorporated in this publication. However, limitations of space and cost had to be considered. It is our hope that the "Handbook of Food and Agriculture" will earn a useful place on the desk of every worker who has to do with foods. The man with easy access to the excellent libraries of large laboratories should find it a convenient *vade mecum*. We have particularly designed this book to meet the needs of the small laboratory or factory with a limited number of reference books. If this volume proves to be a ready source of information otherwise difficult to obtain, the collaborators, the editor, and the Reinhold Publishing Corporation will feel fully rewarded for their efforts.

Pittsburgh, Pa.
March, 1955

FRED C. BLANCK

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1. SOILS

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The purpose of this chapter is to describe the important properties of soils that influence the growth of land plants. Little or no attention will be given to those soil properties and kinds of soil behavior which are of concern chiefly in the use of soil as an engineering material, such as in the construction of roads, as building foundations, and the like. Comprehensive treatises exist in this general field of soil mechanics.

Soil consists of the upper layers of the unconsolidated rock material at the surface of the earth, and serves as the natural medium for the growth of land plants. Soil, at any place, is a natural body which represents the integrated effect of the environmental factors, five of which are recognized, namely, climate, vegetation, parent material, relief, and time. There are many possible combinations of these five environmental factors and, hence, a wide range in properties of resultant soils.

A given soil is a three-dimensional section of the landscape, the properties of which are relatively uniform in either horizontal direction within its area of occurrence. However, the vertical section of the soil, or the soil profile, usually exhibits more or less distinct horizons or zones, due to variations in the influence of environmental factors with depth. Three major horizons are usually recognized in cultivated soils, and other horizons are often present as well. The A horizon, which may consist of one or more subhorizons, represents a layer with an accumulation of organic matter; or it may be a layer that is lighter in color than the underlying horizon and which has lost clay minerals and oxides of iron and aluminum, in which case it is high in such resistant minerals as quartz; or it may be a layer which has both accumulated organic matter and lost clay minerals. The A horizon is most directly exposed to the influence of climate, plants, and animals, including man, and represents the horizon of maximum biologic activity. In soils which have not been cultivated, there may be a layer of more or less decom-

posed organic matter resting on top of the A horizon, which is referred to as A_0 .

The B horizon is characterized by an accumulation of clay and/or oxides of iron and aluminum, with small amounts of organic matter; or it may be a horizon which shows a more or less blocky structure and stronger color in contrast to the horizons above and below; or it may be a horizon that exhibits both enrichment of clay and sesquioxides and a blocky structure with contrasting color. Part of the clay, organic matter and sesquioxides may be derived from the A horizon by downward movement and accumulation.

The C horizon represents a layer below the B horizon which is unconsolidated and relatively little affected by living organisms, and presumably represents material similar in character to that from which the overlying A and B horizons have been developed.

In general, the abundance of roots and microorganisms decreases with depth in the soil profile, and on this account studies of soil properties have been most detailed in the upper horizon. Accurate information on properties of all horizons, however, is important for studies relating to the broad classification of soils and to the grouping of soils for most effective use and management in the production of crops.

Properties of Soil Horizons

Physical Properties. Physical soil properties such as texture, structure and pore space are of major importance in determining water-holding capacity, permeability to roots, air, and water of each horizon, and therefore the suitability of any given soil for producing crops.

Texture refers to the size of soil particles. Texture is essentially constant over a period of years in any given soil horizon. Soil particles are classified on the basis of size into groups called "soil separates." Finest particles are called clay, with the groups of succeedinglly coarser particles being termed silt, sand, and gravel, respectively (Table 1-1). The cohesion and plasticity of a moist soil sample is closely related to its textural composition, and form the basis for recognizing the different textural classes in the field. Most soils consist of a mixture of particles of all size ranges. If the properties of each size group of particles, sand, silt, and clay, are expressed to about the same degree in a soil sample, its texture is designated "loam." The textural names given to soil samples of different mechanical composition are shown in Figure 1-1.

Structure refers to the arrangement of the individual soil particles into aggregates which may differ as to size, shape, and distinctness of development. Very sandy soils often have single grain structure, that is, no aggregates can be recognized. Soil samples high in clay and/or organic matter may show a variety of structural forms. Structure is very important in

TABLE 1-1. SIZE LIMITS OF SOIL SEPARATES FROM TWO SCHEMES OF ANALYSIS*

U. S. Department of Agriculture scheme		International scheme	
Name of separate	Diameter range	Fraction	Diameter range
	<i>mm</i>		<i>mm</i>
Very coarse sand†	2.0-1.0	I	2.0-0.2
Coarse sand	1.0-0.5		
Medium sand	0.5-0.25		
Fine sand	.25-.10	II	0.20-0.02
Very fine sand	.10-.05	III	.02-.002>
Silt	.05-.002		
Clay	Below .002	IV	Below .002

* Soil Survey Staff¹⁸, p. 207.

† Prior to 1947 this separate was called fine gravel. Now fine gravel is used for coarse fragments from 2 mm to 1/2 in. in diameter.

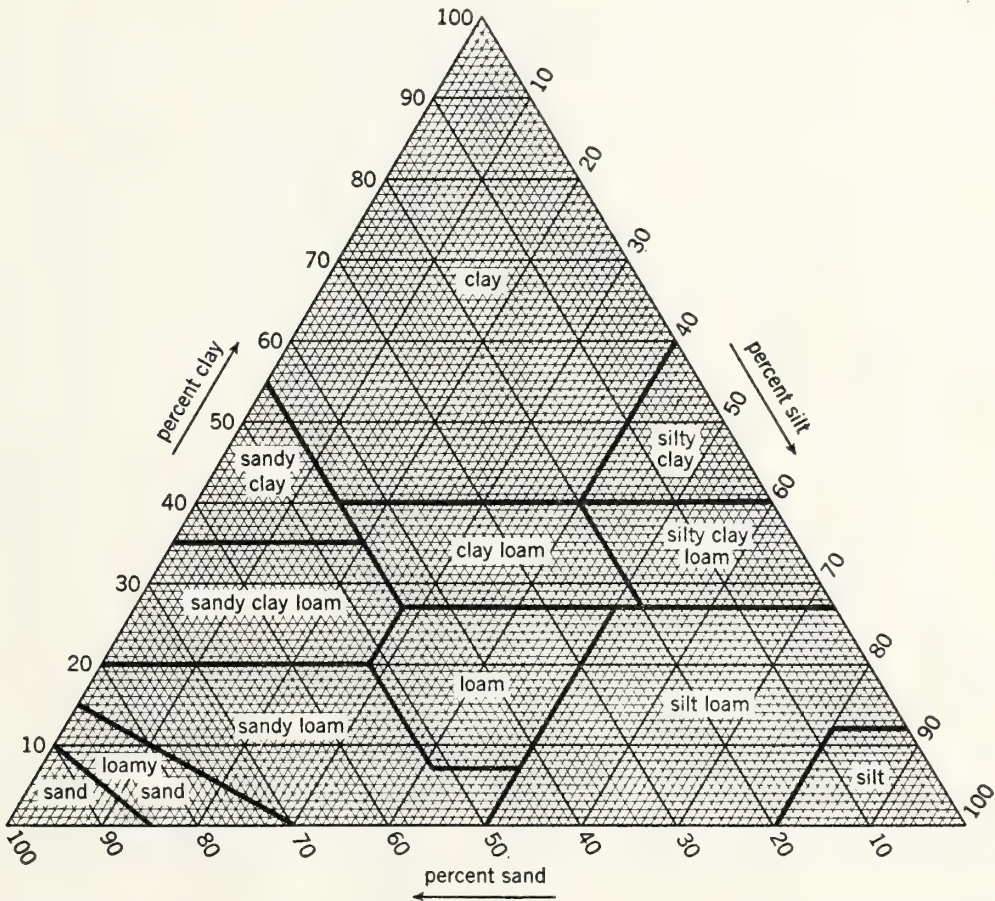


FIGURE 1-1. Guide for textural classification of soils. (Courtesy Soil Conservation Service)

determining the porosity, and hence the permeability of soils, particularly of those high in clay. The terminology for aggregates of different size and shape is given in Table 1-2.

Structural forms in the surface layer of granular or crumb-like nature

TABLE 1-2. TYPES AND CLASSES OF SOIL STRUCTURE*

Class	Platy	Prismlike with two dimensions (the horizontal) limited and considerably less than the vertical; arranged around a vertical line; vertical faces well defined; vertices angular		Blocklike; polyhedronlike, or spheroidal, with three dimensions of the same order of magnitude, arranged around a point		
		Without rounded caps	With rounded caps	Blocklike; blocks or polyhedrons having plane or curved surfaces that are casts of the molds formed by the faces of the surrounding peds	Relatively nonporous peds	Porous peds
		Prismatic	Columnar			
Very fine or very thin	Very thin platy; <1 mm	Very fine prismatic; <10 mm	Very fine columnar; <10 mm	Faces flattened; most vertices sharply angular	(Angular) blocky†	Very fine crumb; <1 mm
Fine or thin	Thin platy; 1 to 2 mm	Fine prismatic; 10 to 20 mm	Fine columnar; 10 to 20 mm	Mixed rounded and flattened faces with many rounded vertices	Very fine subangular blocky‡	Fine crumb; 1 to 2 mm
Medium	Medium platy; 2 to 5 mm	Medium prismatic; 20 to 50 mm	Medium columnar; 20 to 50 mm		Fine granular; 1 to 2 mm	Med. crumb; 2 to 5 mm
Coarse or thick	Thick platy; 5 to 10 mm	Coarse prismatic; 50 to 100 mm	Coarse columnar; 50 to 100 mm		Medium subangular; 10 to 20 mm	
Very coarse or very thick	Very thick platy; >10 mm	Very coarse prismatic; >100 mm	Very coarse columnar; >100 mm		Coarse subangular; 20 to 50 mm	
					Very coarse subangular blocky; >50 mm	

* Soil Survey Staff¹⁸, p. 218

† (a) Sometimes called nut. (b) The word "angular" in the name can ordinarily be omitted.

‡ Sometimes called nuciform, nut, or subangular nut. Since the size connotation of these terms is a source of great confusion to many, they are not recommended.

are usually associated with favorable permeability, even in soils of fine texture such as clays. Subsoil structural forms of a rounded and irregular nature usually indicate higher permeability than forms with sharp angular corners.

Pore space of a soil is that volume not occupied by solids. Texture and structure largely determine the total amount of pore space as well as the size and continuity of pore openings. Friable surface soils average about 50 per cent total pore space, whereas subsoil horizons usually run somewhat below this figure in total pore space.

Pore space in soil is occupied by air and water in proportions that vary reciprocally. In average surface soils in optimum condition for plant growth, the volume composition approximates solids 50 per cent, gas 25 per cent and liquids 25 per cent. Excess moisture in soil displaces air which is essential for proper functioning of most plant roots. Thus, proper drainage of agricultural soils is extremely important for optimum crop production.

Density of soil-mineral particles averages approximately 2.65 g/cc. which is close to that for one of the most abundant soil minerals, quartz. Soil horizons high in organic matter will have an average particle density below 2.65 because of the low density of organic matter itself. Bulk density, or volume weight of a soil horizon is influenced both by the specific gravity of the soil particles and the total pore space. A representative value for bulk density of surface samples is 1.3 g/cc. Subsoil samples average somewhat higher, in extreme cases going as high as 2 g/cc.

Soil temperature is important in relation to root activity, microbiologic activity, and rate of chemical transformations. However, measures to control soil temperature are usually incidental to the accomplishment of other purposes. Drainage to remove excess water will permit the soil to warm up more rapidly in the spring, since the specific heat of soil particles averages about 0.2 as compared to water. Surface covers (mulches) of crop residues such as straw or building paper used to reduce evaporation and control weeds in special situations, will keep the soil cooler in summer and warmer in winter. Dry soil is a poor heat conductor; wet soil conducts heat somewhat better but still at a slow rate, and presence of water increases the specific heat of the soil mass; therefore, subsurface and subsoil temperatures are lower in spring and summer and higher in fall and winter than surface soil and air temperatures. Furthermore, the magnitude of daily and seasonal temperature fluctuations decreases rapidly with depth, and subsoil temperatures at moderate depths are about constant.

Soil air usually is somewhat higher in carbon dioxide and lower in oxygen than the atmosphere; also, the humidity of soil air approaches 100 per cent most of the time except in the surface layer under extremely dry conditions. Removal of carbon dioxide and renewal of oxygen in soils is dependent

TABLE 1-3. CHEMICAL COMPOSITION OF REPRESENTATIVE SURFACE SOILS

	Clinton ¹ silt loam, Iowa	Cecil ¹ fine sandy loam, N. C.	Tama ¹ silt loam, Iowa	Mohave ¹ loam, Ariz.	Nipe ² clay, Cuba
SiO ₂	79.57	88.02	70.80	67.44	3.28
TiO ₂	0.63	0.22	0.69	0.60	0.80
Fe ₂ O ₃	2.34	.76	3.82	5.31	63.04
Al ₂ O ₃	8.86	4.47	11.48	14.40	18.46
MnO	0.20	0.01	0.13	0.10	0.42
CaO	.75	.04	.98	2.04	.12
MgO	.61	.07	.92	1.52	.33
K ₂ O	2.03	1.19	2.05	2.72	.06
Na ₂ O	1.48	0.35	0.93	1.73	.47
P ₂ O ₅	0.07	.02	.18	0.22	.03
SO ₃	.05	.05	.15	.10	—
Ignition loss	3.70	4.63	8.39	3.35	12.74
N	.10	0.07	0.24	0.03	0.02
Organic matter	—	—	—	—	1.02

¹ Data from Marbut¹².

² Data from Bennett and Allison².

largely on diffusion, the rate of which is influenced by the size and continuity of those pore openings not filled by water.

Chemical Properties. Analyses of several representative surface soils from the United States and one from Cuba are given in Table 1-3. In addition to the constituents listed in Table 1-3, most soils contain small quantities of many other elements; in fact, spectographic studies show most elements to be present in at least trace quantities.

Silica is the major constituent of most soils in the temperate to cool regions, with aluminum oxide and iron oxide, respectively, being next in amount. Many soils of equatorial and tropical regions, such as the Nipe from Cuba, are relatively low in silicon dioxide and consist chiefly of sesquioxides. Soils of dry regions are usually higher in basic elements, such as calcium, magnesium, potassium, and sodium than soils of humid regions which are subject to greater leaching; furthermore, the larger soil particles in humid regions tend to consist of quartz or other very resistant materials; in dry regions differentiation in composition between coarse and fine particles is less pronounced.

Loss on ignition represents chiefly organic matter plus water of hydration and constitution. Approximate values for organic matter content can be obtained by multiplying the per cent nitrogen by 20. Organic matter includes all plant and animal residues in soils, as well as the various decomposition products therefrom. Organic matter content is higher in cool regions than in warm regions because the rate of decay is slower at low temperatures. Organic matter is higher in the subhumid grassland regions than

in the arid regions because of greater plant growth at higher moisture levels. Organic matter is often high in wet and swampy soils because excess water excludes air (O_2) necessary for rapid decay.

Most of the sulfur and nitrogen and part of the phosphorus in soils are found in the organic fraction. Subsoil layers usually are lower in organic matter, and hence in nitrogen and sulfur than surface layers. In humid portions of temperate regions, subsoil layers are lower in silica and higher in sesquioxides than the surface, whereas in dry regions subsoils usually contain accumulations of calcium and magnesium carbonates. Little variation in composition with depth is observed in such soils as the Nipe in Cuba which is very high in sesquioxides.

In soils of humid regions, practically all of the elements exist in such insoluble forms as quartz, alumino-silicates (feldspars, mica, clay minerals), sesquioxides, apatite and organic matter. In soils of arid regions, other materials of a more soluble nature occur in addition, such as calcium and magnesium carbonates, gypsum, and even small quantities of sodium carbonate, sodium chloride, and potassium sulfate in situations where drainage water accumulates and evaporates.

Total analysis of a soil sample indicates the total reserves of fertility present. However, most essential elements must be in soluble or even ionic form to enter plant roots, thus total analysis alone is not a suitable criterion of the amount of any element available to plants. The rate of transformation of insoluble to soluble forms, in relation to rates of plant removal and leaching, must be considered. Details relating to formation of compounds and ions available to plants are given in Chapter 2 on Soil Fertility.

Fifteen elements are recognized as essential for plant growth. The three used in greatest quantities, carbon, hydrogen and oxygen are obtained chiefly from water and air; the other twelve are obtained entirely, or in part, from the soil. The elements nitrogen, phosphorus, potassium, calcium, magnesium and sulfur are used in relatively large quantities by plants, whereas iron, copper, boron, manganese, zinc and molybdenum are needed only in very minute quantities, and often are referred to as "trace" elements. Other elements occurring in soluble or available forms in the soil, in particular silicon, aluminum and sodium, are usually found in plant tissue but have not been proved essential for plant growth.

The essential element most commonly deficient for optimum plant growth in agricultural soils is phosphorus. Deficiencies of nitrogen are equally widespread for nonlegume crops which depend entirely on the soil for nitrogen supplies. Soils of humid regions usually are deficient in available calcium, magnesium and potassium, though the total quantities present, in many instances, as shown by total analysis (Table 1-3) would seem to be adequate. In humid regions the soluble and available forms of these basic elements

are leached from the soil and deficiencies for plant growth thereby result. Commercial fertilizers used in humid regions are formulated to provide chiefly the elements nitrogen, phosphorus, and potassium. In arid regions fertilizers provide chiefly nitrogen and phosphorus. In humid regions calcium and magnesium are supplied chiefly in liming materials. Deficiencies of sulfur, iron, copper, boron, manganese, zinc and molybdenum are observed less frequently and, in general, cannot be predicted from total analyses of soil samples. (See Chapter 4 on Fertilizers and Chapter 2 on Soil Fertility).

Colloidal Properties. From the colloidal viewpoint all soils except those consisting entirely of sand and/or silt, may be considered as modified gels when at a moisture content suitable for plant growth. Soils differ from gels in possessing a third phase (gas) and in containing more or less noncolloidal material (sand and silt). The major groups of colloidal materials present in soils include the following:

- (1) "humus" (organic colloids)
- (2) mineral colloids
 - (a) alumino-silicates
 - (b) hydrous oxides
 - (c) miscellaneous

The major properties of each group that significantly affect soil behavior will be outlined briefly.

"Humus". This is a black, amorphous, nonplastic material which occurs chiefly as a coating on mineral soil particles. It is decomposed only slowly by microorganisms. Humus averages about 50 per cent carbon and 5 per cent nitrogen, with smaller quantities of phosphorus and sulfur. Humus consists of many compounds, few of which have been well-defined as to composition and structure. A lignin-like fraction is abundant in humus, and polyuronides have been identified as a constituent. Humus possesses a high cation exchange capacity at pH 7 (200–250 milliequivalents per 100 grams). The acidic groupings which account for this exchange capacity probably are carboxyl, phenolic hydroxyl, and perhaps several others.

From a colloidal viewpoint humus properties are analogous to those of soaps in many ways. Calcium salts are completely insoluble and flocculated; sodium salts are highly dispersed; humic acids are slightly dispersed. The lyotropic series of the major soil cations for flocculation is $\text{Ca} > \text{Mg} > \text{H} > \text{K} = \text{NH}_4 > \text{Na}$. Humic materials tend to act as protective colloids in soils, and where calcium and magnesium are the dominant exchangeable cations, humus will stabilize soil structure.

Alumino-silicates. These are dominantly plate-shaped microcrystalline particles which exhibit high plasticity in the gel condition, as do all gels consisting of rod or plate-shaped particles. The crystal structure is of two

major types, the so-called 1:1 structure characteristic of kaolinite, and the 2:1 structure characteristic of montmorillonite and illite. The 1:1 unit structure may be visualized as a sheet of Al ions within an octahedral arrangement of O and OH ions, held by shared O ions to a second sheet consisting of Si ions which are within a tetrahedral arrangement of O ions. The external surface of the alumina sheet consists entirely of OH ions, whereas the external surface of the silica sheet consists of O ions. Adjacent unit structures of the 1:1 type are held together strongly by hydrogen bonding between the layer of OH ions and the adjacent layer of O ions. Thus, crystals of the 1:1 structure type form relatively large colloidal particles that are very stable. Very few cation substitutions, such as Al for Si or Mg for Al, occur within the crystal lattice to give a net negative charge to the lattice that would be balanced by exchangeable (surface) cations. Cation exchange capacities at pH 7 are low being of the order of magnitude of 10 milliequivalents (ME) per 100 grams.

The 2:1 unit crystal structure consists of one alumina sheet "sandwiched" between two silica sheets, the three sheets being held together by shared O ions. Adjacent unit structures of the 2:1 type are held together less strongly than those of the 1:1 type since there is much less possibility for H-bonding. In certain 2:1 type crystals like montmorillonite, the forces of surface attraction between unit structures are so weak that the units separate enough in water to permit exchangeable cations to penetrate between adjacent unit structures. Ionic substitutions, such as Al for Si and Mg for Al, are very common within the 2:1 type crystal lattices. The excess negative charge resulting from such substitutions is balanced with cations that are exchangeable. Cation exchange capacity values at pH 7 for 2:1 structures are, in general, higher than 1:1 structures and in the case of montmorillonite, may reach values approaching 90 to 100 ME per 100 grams.

The lyotropic series for flocculation of all alumino-silicate colloids is $H > Ca > Mg > K = NH_4 > Na$. The reason that H is displaced from its expected position between Mg and K is that H ions dissolve or displace Al ions from the lattice, at corners and edges particularly. Trivalent Al ions then become exchangeable ions and the colloidal system is really an H (Al) rather than an H system. On this account, in the absence of humus, alumino-silicate colloids form less stable aggregates when the exchangeable ion is calcium than when it is dominantly hydrogen.

Hydrous Oxides. This group includes colloidal particles consisting of oxides and hydroxides of iron, aluminum, titanium and manganese, and perhaps other elements. Hydrous oxide colloids appear to be amorphous, exhibit low plasticity, and possess no cation exchange capacity at pH 7. They do show anion exchange with phosphate, arsenate, and to a lesser degree with sulfate, particularly below pH 7. Mutual flocculation effects

are observed with oppositely charged (negative) alumino-silicate and humus colloids. Drying also causes flocculation. Once flocculated, hydrous oxide colloids are difficult to disperse. Thus, if they are present in appreciable quantities they tend to produce stable soil aggregates and structure.

Miscellaneous Group. In general, this group seldom exerts significant influence on soil properties and behavior. It consists mostly of colloidal silica and partly weathered mineral fragments of colloidal dimensions.

Biological Properties. A great variety of living organisms exist in soils of the world. Plant roots usually represent the largest total mass of living material in ordinary soils. Large animals, such as earthworms, insects, rodents, and the like, are found in many if not most soils. In addition, microorganisms in a great profusity of kind and number are always present. These include small animals such as nematodes and protozoa, as well as small plants such as fungi, bacteria, and actinomycetes.

The entire population of soil organisms bears two major and very significant functional relationships to soils and soil properties. First, soil organisms including crop plants and their roots, synthesize organic compounds and constitute the source of organic matter in soils. Secondly, soil organisms bring about the decomposition of organic material that accumulates in the soil. Such decomposition is important in the prevention of undue residue accumulation as well as in making available for future plant generations the nutrients contained in the organic residues. Soils would soon become a tangled mass of dead plant remains were it not for the decomposition activities of soil organisms.

Higher plants, including crop plants, are influenced in a very significant way by three functional relations of the soil microorganisms. The first of these is that of symbiosis which is best illustrated by the nitrogen fixing bacteria in legume root nodules. The activity of bacteria in legume nodules accounts for a large portion of the nitrogen available for crop production. A second important relationship is that of pathogenesis; and the control of disease-organisms in the soil is an important aspect of soil management. Thirdly, microorganisms compete with crops for available nutrients in the soil. When fresh residues of highly carbonaceous nature, such as straw, are turned under, the competition for available nitrogen between crops and microorganisms may be so extreme that the crop will be seriously retarded in growth. Details about the behavior of microorganisms in the soil are given in Chapter 3 on Soil Microbiology.

Exchangeable Cations in Soils. The kind and proportion of exchangeable cations held by soil colloids (humus and alumino-silicates) have a controlling influence on (1) soil fertility, (2) soil reaction (pH), and (3) soil structure.

The usual order of abundance of exchangeable cations in soils of dry

regions is $\text{Ca} > \text{Mg} > \text{K} > \text{Na}$; in humid regions it is $\text{H} \approx \text{Ca} > \text{Mg} > \text{K} > \text{Na}$ (unless the soil has been limed). Other exchangeable cations exist on soil colloidal surfaces in small to minute quantities, but usually are not reported in analyses for exchangeable cations. Most soils contain measurable quantities of exchangeable NH_4 because NH_4 is produced during organic matter decay. The NH_4 ion is oxidized to NO_3 by microorganisms as well as being used directly by some plants, hence the amount, even though very small, varies greatly throughout the year. Exchangeable aluminum occurs in acid soils in quantities that, even though very small, often are sufficient to be toxic to certain plants. In addition, exchangeable iron, copper, manganese, zinc and perhaps other cations occur in very small quantities.

In most soils exchangeable cations represent the major available reserve of those essential elements which occur in cationic form. The availability of any cation depends on the proportion of the total soil cation exchange capacity occupied by the ion (per cent saturation) and the relative abundance of the other cations. The critical per cent saturation and the critical ratios vary with the cation and the crop. Optimum per cent saturation for many of the crops commonly grown in humid regions are: $\text{Ca} = 65$, $\text{H} = 20$, $\text{Mg} = 10$ and $\text{K} = 5$. Calculating these quantities in terms of pounds per acre found in the 6-in. furrow slice for a soil with a cation exchange capacity of 10 ME per 100 grams, gives the following values: $\text{Ca} = 2600$ lb.; $\text{H} = 40$ lb.; $\text{Mg} = 240$ lb.; $\text{K} = 390$ lb. One of the major problems of soil fertility is to maintain the level and balance of exchangeable cations (through use of lime and fertilizers) within a range suitable for the crops being grown (see Chapter 2 on Soil Fertility).

The Soil Reaction (pH). Soils of dry regions usually have pH values above 7. Where calcium is the dominant exchangeable cation the maximum pH attained when the soil is in equilibrium with carbon dioxide of the atmosphere is about 8.5. Samples containing appreciable quantities of exchangeable sodium (15 per cent saturation and upward) may have pH values as high as 9 or even 10 unless the concentration of soluble salts is considerable, in which case the salts repress dissociation of Na from the colloid and the pH does not rise so high.

Soils of humid regions usually have pH values below 7. Under conditions of extreme leaching, hydrogen may represent 90 per cent or more of the total exchangeable cations. If the total cation exchange capacity of the soil is not extremely low (5 ME per 100 grams or above) the minimum pH value observed depends primarily on the acidic strength of the colloids present. Humus and montmorillonite are relatively strong acids with illite and kaolinite being successively weaker. Soils high in humus may have pH values as low as 3. Soils high in kaolinite seldom have a pH below 4.5, while samples

high in illite may be more strongly acid. Montmorillonite usually is not abundant in strongly acid soils; however on electro-dialysis montmorillonite will reach a pH of 3; on standing, however, the pH rises probably due to the release of aluminum and perhaps other cations from the lattice by hydrogen.

Crops vary greatly in their sensitivity to soil pH. Some grow well over a narrow range only; others tolerate well a very wide range in pH. The optimum pH range for most crops is 6 to 7, partly or perhaps largely because in this range control of soil fertility is most easy. Fertilization, leaching, and biologic activity all tend to cause changes in soil pH values during the season unless the soil is well buffered. Humus and alumino-silicate colloids act as good buffers over a considerable pH range. The degree of buffering in the soil is roughly proportional to the total cation exchange capacity.

Soil Structure Control

Soil structure influences significantly soil permeability and soil erosion. Very sandy (coarse textured) soils, even though "structureless" (single grain structure), usually are readily permeable to roots and water; however, they are easily eroded by moving surface water. Fine-textured soils (those high in clay) will have small pores and usually low permeability unless they possess a favorable structure that is stable under conditions of high moisture; fine-textured soils are usually less easily eroded than very sandy soils. Slowly permeable soils usually absorb rainfall slowly and during heavy showers runoff is to be expected on slopes with attendant erosion hazards.

The two general problems of soil structure control are first, to develop favorable structure in those soils which have such potentialities, and second, to stabilize the favorable structure which is inherently present or has been created, so that it will persist in spite of the dispersive action of rainfall impact and tillage operations. Dispersed soil particles readily clog soil pores, and retard water entry; also dispersed particles are easily suspended and carried away in moving water that is not able to penetrate soils.

All soil colloids exhibit cohesion and may serve as binding agents in the formation of structural aggregates, but aggregate stabilization is more difficult. Structural stability is favored by (1) presence of at least moderate amounts of humus with calcium and magnesium as the dominant exchangeable cations, as in dark-colored (chernosemic) soils of the natural grasslands in cool climates (2) high content of hydrous oxide colloids as in red (latosolic) soils of hot regions. It is impractical to attempt to control the hydrous oxide colloid content of soils. The addition of organic matter and lime to soils, however, is a practical procedure in some regions to help stabilize soil structural aggregates.

Soils of high structural stability may be cultivated more frequently

without serious impairment of permeability or serious erosion hazards than soils with less stable structures. Of course, where erosion and/or permeability problems are serious, pasture crops or even forests may need to replace cultivated crops entirely. Exposed subsoil layers low in humus and relatively high in alumino-silicate colloids offer serious tillage problems. Gradual structural improvement may be expected with an increase in humus as may occur slowly under sod crops.

In non-saline soils with a sodium saturation of 15 per cent or more, colloid dispersion and pH become high and the structure is extremely unstable. Such soils are uncommon in humid regions but are of frequent occurrence in subhumid to arid regions. Saline (salty) soils high in exchangeable sodium are not dispersed, however, because the soluble salts lower the zeta potential below the critical value for flocculation of the colloids. Usually, however, saline soils are not suitable for crop production (under irrigation) until soluble salts are leached. In soils high in exchangeable sodium, economic crop production usually depends on replacement of exchangeable sodium (commonly using gypsum) until it is below the critical level (less than 15 per cent saturation) with consequent lowering of pH and increased stability of structure. Irrigation waters containing a high proportion of sodium to calcium may raise the per cent saturation of sodium in soil above the critical level (see Richards *et. al.*¹⁵).

Soil Conditioners. Recently synthetic chemical compounds that influence the structural properties of many soils have been made available commercially. Pearson and Jamison¹⁴ have classified the products currently on the market into the following categories: (1) polyvinylites, (2) cellulose gums, and (3) lignin derivatives. The study of these materials has been initiated on a widespread basis, but evaluation of their effects on different soils is far from complete. Tentative conclusions about several of the conditioners, based on data currently available, have been summarized by Pearson and Jamison¹⁴.

Soil Moisture

Plants depend directly on soil for a supply of water. Important soil moisture relations include: (1) retention of water by soils, (2) availability of soil moisture to plant roots, and (3) moisture movement within soil as it affects recharge of lower horizons and disposal of excess by percolation.

One of the major forces that holds water in soil against the force of gravity is the attraction between soil particles and water molecules. For very thin films of water only a few molecules thick, this force may reach a magnitude of 10,000 atmospheres. The force between the water molecule and the soil surface decreases as the thickness of film increases. For convenience of discussion, soil water is classified broadly on the basis of the

energy with which it is held by soil particles. The thin portion of the film which is very tightly held by attractive surface forces and thus under great tension, is referred to as hyroscopic water; it can move only by distillation and condensation. Capillary water is that portion held under a lesser tension which moves through the soil pores in response to differences in surface tension, which varies with the radius of curvature of soil particles and water films. Water which moves downward under the influence of gravity is least tightly held and is referred to as gravitational water.

The force or tension under which the water exists in the soil may be expressed in atmospheres or on the pF scale. The pF is the common logarithm of the height, measured in centimeters, of a water column which will exert a force equivalent to the tension on the soil moisture. One atmosphere is approximately equal to a 1000 cm. of water or a pF of 3. The range in pF of hygroscopic water is from 4.5 to about 7. The pF of capillary water ranges from 4.5 downward. The separation between capillary and gravitational water is not a fixed value but depends on the height of the soil column which is being drained. For a very short column, say 1 cm, the pF of water held against gravity would be approximately 0 (1 g/sq cm). With deeper soil columns the tension on the water at the top of the columns is increased by the weight of the water column formed by the continuous water films around the soil particles. Thus, when moisture equilibrium is reached after a soaking rain, the pF in the soil column is 0 at the water table and reaches a value between approximately 1.0 and 1.5 at the surface, depending on the height and the permeability of the column.

Available water is that which plant roots can absorb from soil, chiefly by osmosis. The osmotic pressure of most root cells approximates 15 atmospheres (pF about 4.2). In soils with a very low concentration of soluble salts, as in humid regions, available water includes that portion of the films under a tension of less than 15 atmospheres. If soluble salts are present, as in arid regions or immediately after heavy fertilization, the resultant osmotic force is directly additive to the tension of the water film and less of the total soil water is available to plants. Most plants make optimum growth when the total stress on the soil moisture is low, probably in the range of 1 to 5 atmospheres in the layers penetrated abundantly by plant roots.

Water movement rates decrease rapidly in soils as the tension rises. Above approximately $\frac{2}{3}$ atmosphere the rate of capillary adjustment becomes very slow and is not rapid enough to supply water to plant roots effectively over distances greater than a few inches. Thus, roots must actually penetrate soil layers to utilize much of the available water stored there. High water-supplying capacity of the soil is particularly important to efficient crop growth during periods of drought. High water-supplying capacity is associated with deep soils (including A, B, and C horizons) which have continuous pore openings of such size that water may percolate freely after

rain, permitting entry of air to encourage vigorous root growth and penetration. Such soils either have medium textures of the fine sand to fine sandy loam classes or fine textures with structures which provide a similar kind of pore system throughout the entire profile.

Classification and Geography of Soils

The definition, distribution, and more important properties of the major broad groups of soils will be presented in this section. Soil science is very young, and it should be recognized that soil classification, consequently, is tentative and in process of revision and improvement. The present soil classification system used in the United States arranges all soils into three broad groups: zonal, intrazonal, and azonal soils.

Zonal soils have attained approximate equilibrium with the environment. They have developed under conditions of good drainage from parent materials which are medium in texture, and of mixed mineral and chemical composition. Zonal soil properties reflect rather fully the influence of the climatic and biologic forces. The several groups of zonal soils consequently have a geographic distribution that correlates closely with the distribution of climate and natural vegetation.

Intrazonal soils also have attained approximate equilibrium with the environment, but have developed under conditions of restricted drainage or from parent material of extreme character, which has limited the degree to which climatic and biologic forces have affected soil properties. Distribution of intrazonal soils, therefore, correlates less closely with the distribution of climate and vegetation, and a given intrazonal soil may occur in two or more climatic and vegetative zones.

Azonal soils are too young to have attained equilibrium with the environment and these soils have little or no differentiation throughout the profile. Such soils are found on recent alluvial deposits formed along streams, and also on steep slopes where the rate of geologic erosion exceeds the rate of soil profile development. Azonal soil distribution is not correlated closely with climatic and vegetative patterns.

The pattern of occurrence of zonal, intrazonal, and azonal soils usually is very intricate and detailed and can be shown accurately only on maps of very large scale. Small-scale maps, such as for the United States or the world, usually indicate only the distribution of broad groupings of zonal soils. The associated intrazonal and azonal soils, while differing from the zonal soils in many features, will have a number of important properties in common with them. Orvedal, Kubota, and Smith¹³ have published a soil map of the world on which the distribution is shown of five broad groups of zonal soils (Figure 1-2). A brief summary of the more important properties of each broad zonal group shown in Figure 1-2 follows.

Tundra soils occur in cold climates with average annual temperatures

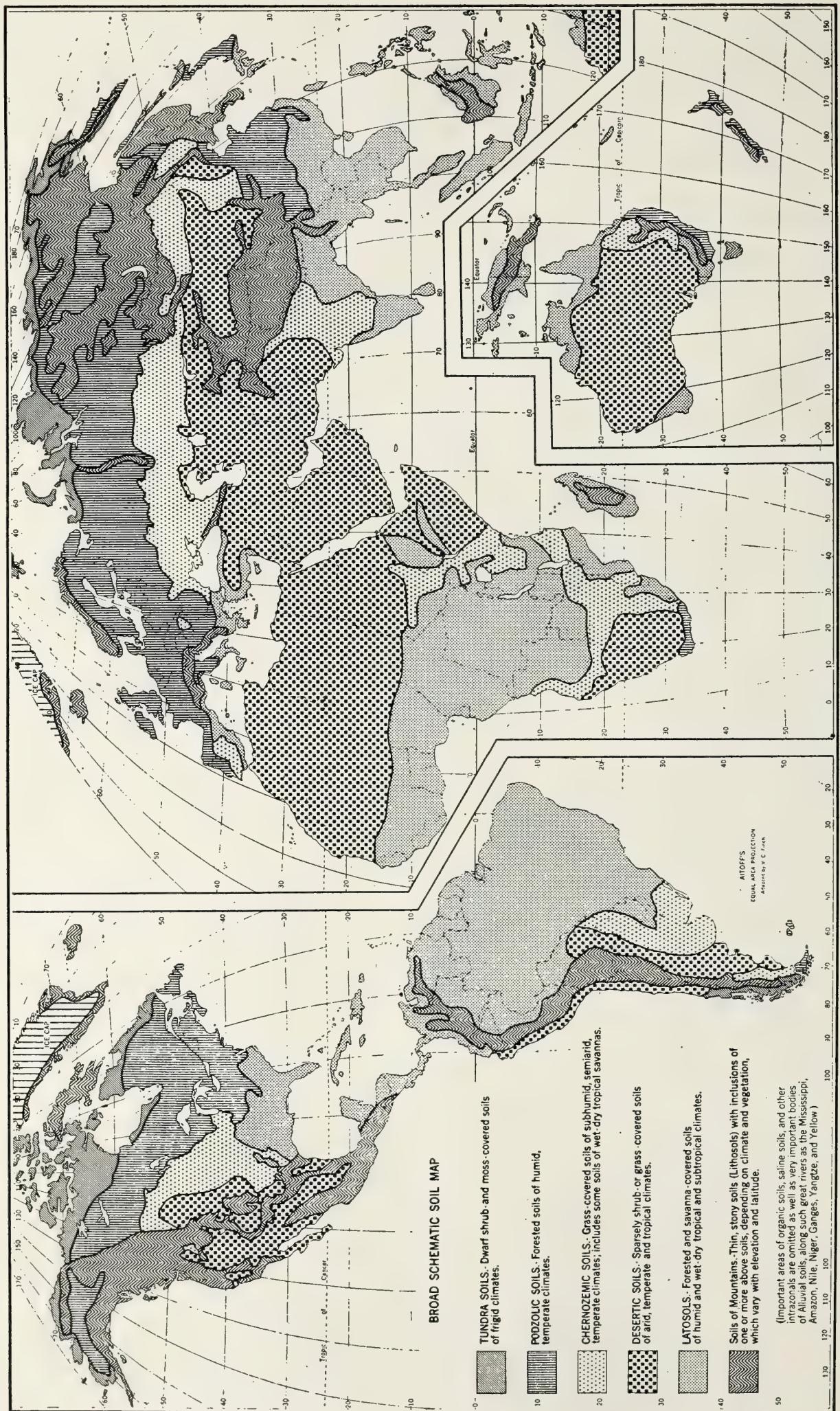


Figure 1-2. Broad schematic soil map of the world. (Courtesy Conservation Service)

close to or below freezing in areas of low precipitation; in areas of high precipitation, permanent snow fields usually occur. Usually there is a permafrost zone in the subsoil. The frozen horizon prevents percolation of water; therefore on level areas Tundra soils are very wet. The low temperature limits both physical and chemical weathering as well as biologic activity. Tundra soils have not been well studied, and information about them is limited.

Podzolic soils occur in the temperate to cool humid regions which are or were originally forested. They are low in organic matter except for the uppermost 1 to 3 in. of virgin areas, (see data for Clinton and Cecil soils, Table 1-3), and usually are light in color. Leaching is pronounced and the soils are medium to strongly acid. Clay and/or sesquioxides have been re-



(Photograph by R. W. Simonson)

Figure 1-3. Ruston sandy loam. Red-yellow Podzolic soil.

moved from the A horizons and accumulated in part in the B horizons, giving a sharp contrast in texture (see Figure 1-3). The mineral colloidal materials present are dominantly of the illite and/or kaolinite types. However, hydrous oxides may be abundant in the B horizons of certain soils (Podsols) developed on very sandy materials in the colder regions. Cation exchange capacities are medium-low except in B horizons of fine texture where they may be medium to medium-high. The associated intrazonal soils developed under restricted drainage include peat bogs as well as soils with fine-textured compact and slowly permeable B horizons.

Latosols occur in the very warm humid regions. These soils are dominantly red to brown in color, low in organic matter, and deeply weathered and leached (see data for Nipe soil, Table 1-3.) The mineral colloids are dom-



(Photograph by R. W. Simonson)



(Photograph by R. W. Simonson)

Figure 1-4. Tama silt loam. Chernosemic soil.

Figure 1-5. Edina silt loam. Intrazonal soil of the Chernosemic region.

inantly of the hydrous oxide group, though kaolinite may occur in many cases. Because of low-cation exchange capacity throughout the profile, pH values seldom fall below the moderately acid range. Phosphate fixation (anion exchange) usually is pronounced. On the more siliceous parent materials and particularly in the transition zone to cooler climates, soils similar to those of the podzolic group are to be found.

Chernosemic soils occur in the subhumid to semiarid grassland areas. These are dark-colored soils relatively high in organic matter in both the A and B horizons (see data for Tama soil Table 1-3). The surface layers are slightly acid to neutral. Subsoil horizons usually are alkaline and often have an accumulation of calcium and magnesium carbonates. The B horizon is only slightly heavier in texture than the surface, but usually has a blocky structure in contrast to the granular surface structure (see Figure 1-4). Mineral colloids are dominantly montmorillonite and/or illite types. Cation exchange capacities are relatively high. The associated intrazonal soils frequently have fine-textured, slowly permeable B horizons.

Desertic soils occur in arid climates under sparse vegetation. Horizons usually are thin, organic matter content low, and the soils are relatively light in color (see data for Mohave soil, Table 1-3.). The profile is alkaline throughout with accumulations of calcium and magnesium carbonates. In many instances calcium sulfate accumulations are found. The mineral colloids are chiefly of the montmorillonite and/or illite types, but the total quantity of clay present ordinarily is not large because of the limited chemical weathering associated with dry conditions; thus, the cation exchange capacities are medium-low. The associated intrazonal soils usually are saline (salty) or else are strongly alkaline.

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2. SOIL FERTILITY

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The purpose of this chapter is to discuss the factors affecting the fertility status of soils. Soil fertility refers to the nutrient supplying properties of a soil which enhance plant growth. Soil fertility and soil productivity are not the same. Productivity is the ability of a soil to produce certain crops. Productivity is a function of a soil's fertility, present naturally or obtained artificially through application of manures and commercial fertilizers; of its physical properties; of its climate; and of soil management and other noninherent factors used to produce crops.

Changing the pattern of soil management may change the fertility and productivity of a soil. Under good management, maximum use is made of the fertility status of a soil; poor management uses only part of a soil's ability to produce given crops. Therefore, a soil may be fertile but not productive, though it can hardly be productive without being fertile. Productivity, then, is the true measure of an agricultural soil.

The fertility of cultivated soils is never fixed. The harvesting of crops, leaching by rain water, and soil erosion decrease soil fertility. On the other hand, weathering of soil minerals; application of manures, fertilizers, lime and fungicides; the growing of legumes; and such substances as nitrogen and sulfur, carried down by the rain, add nutrients to the soil.

Some soils are able to provide all the essential elements for plants. Other soils may have an overabundance of one or more elements or compounds and a deficiency in one or more. Certain elements or fertilizer compounds are needed for maximum crop productivity and to maintain and improve the productivity of the land.

Soil and Plant Fertility Relationships

A soil to produce crops successfully must have an adequate supply of nutrients. The nutrient elements required for plant growth are given in

Chapter 1. These elements must be present in forms that plants can use as well as in proper amounts for normal growth. A deficiency or excess of one or more element may produce stunted or abnormal plant growth and result in reduced yields. Various techniques for diagnosing the fertility status and nutritional requirements of crops have been published elsewhere⁴².

The mobility of nutrients in soils is one of the most important single factors in soil fertility relationships¹⁹. The term "mobility" includes the processes whereby nutrient ions reach the plant root surfaces making possible their sorption or uptake into the plant.

Available forms of nutrients in soils may be divided into two groups. One group consists of nutrients relatively mobile in the soil, like nitrate nitrogen; the other consists of nutrients relatively immobile like exchangeable potassium and the adsorbed forms of phosphate.

Plant uptake of nutrients in relation to their mobility has been divided into two groups by Bray¹⁹. The most mobile nutrients will be effectively obtained from the soil occupied by the major part of the root system, called the *root system sorption zone*. The other zone, called the *root surface sorption zone*, is adjacent to each root, or root hair surface, from which the

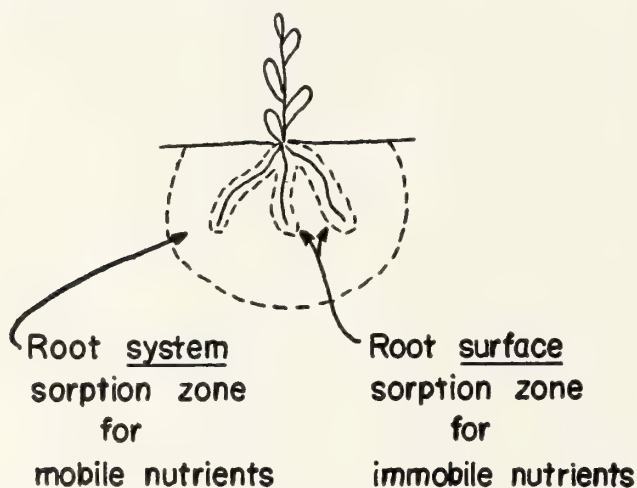


Figure 2-1. Root sorption zones. (Courtesy of R. H. Bray, Ill. Agr. Exper. Sta.)

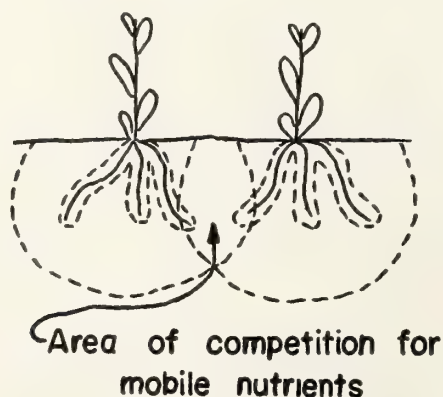


Figure 2-2. Root system sorption zones overlapping. (Courtesy of R. H. Bray, Ill. Agr. Exper. Sta.)

roots effectively obtain the relatively immobile nutrients. These two kinds of zones are schematically illustrated in Figure 2-1.

Competition for nutrients may be divided into three stages¹⁹. When plants are spaced far apart their root sorption zones do not overlap or interpenetrate each other and no competition for nutrients (or water) occurs. Competition for the relatively mobile nutrients occurs when the root *system* sorption zones of adjacent plants interpenetrate (Figure 2-2). Competition for the relatively immobile nutrients occurs only as the root *surface* sorption zones interpenetrate (Figures 2-3 and 2-4). Depending on the planting patterns, rate of planting, soil moisture, and physical nature of the soil, plants can grow (a) without competing with each other for any nutrients, (b) effectively competing for the relatively mobile nutrients

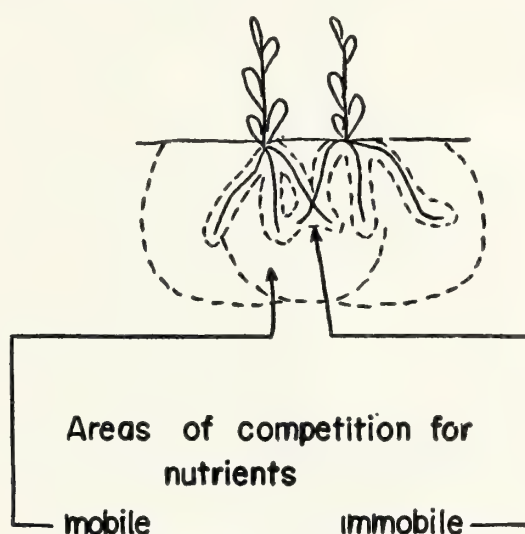


Figure 2-3. Root surface and root system sorption zones overlapping. (Courtesy of R. H. Bray, *Ill. Agr. Exper. Sta.*)

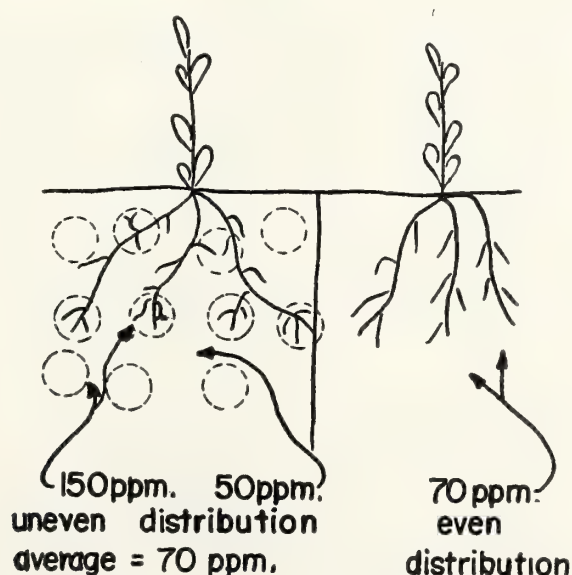


Figure 2-4. Fertility patterns having same soil level of an immobile nutrient. (Courtesy of R. H. Bray, *Ill. Agr. Exper. Sta.*)

only, and (c) competing for both the relatively mobile and relatively immobile nutrients.

Because the mechanism of the entry of ions into plant roots is in the field of plant physiology, this phenomenon will not be discussed here.

Soil pH and Nutrient Availability to Plants

Soil acidity or alkalinity may exert an unfavorable influence on crop growth. Plants vary greatly in their preference and tolerance of soil pH. For example, the most favorable pH range for alfalfa is considerably higher than that of timothy.

Few crop plants grow below pH 3.5 or above pH 9.0. The most favorable pH range for most crop plants is 6.2 to 7.2⁹. Arnon *et al.*³ have shown that plant roots are definitely injured in solutions as acid as pH 3 and are unable to absorb calcium and phosphate; at pH 9 phosphate absorption is drastically curtailed. The tolerance of plants to acid and alkaline conditions in soils is given in Tables 2-1 and 2-2. Comprehensive lists may be found in publications by Spurway⁸⁵ and Hartwell and Damon³⁶. There are marked differences in relative salt tolerance among various genera, species and varieties of agricultural crops³⁷. Small⁸⁴ has discussed the effect of pH on plant growth in detail.

Soil reaction exerts an indirect influence on plant growth in its effect on the availability of plant nutrients¹⁰¹. Strong acidity and strong alkalinity in general decrease the availability of many plant nutrients while very slight acidity (about pH 6.5) is favorable. Figure 2-5 presents the subject diagrammatically¹⁰⁰.

At strong acidity, the availability of some nutrients drop markedly, for

TABLE 2-1. RELATIVE SENSITIVENESS OF PLANTS TO ACID SOIL CONDITIONS

Very tolerant	Tolerant	Sensitive	Very sensitive
Blueberry*	Alsike clover	Barley	Alfalfa
Cowpea	Buckwheat	Bluegrass	Asparagus
Cranberry*	Corn	Cabbage	Beet
Fescue	Cotton	Cauliflower	Celery
Lupine	Crimson clover	Egg plant	Lettuce**
Millet	Cucumber	Muskmelon	Onion**
Oats	Grape	Orchard grass	Parsnip
Peanut*	Rhubarb	Red clover	Pepper
Potato	Strawberry	Sweet clover	Quince
Red top	Tomato	Turnip	Salsify
Rye	Timothy	Tobacco	Spinach**
Watermelon*	Vetch	Wheat	Yellow trefoil

Reprinted by permission of F. E. Bear from "Soils and Fertilizers," John Wiley and Sons, Inc., N. Y., 1953.

* Especially tolerant of acid soil conditions.

** Especially sensitive to soluble aluminum.

TABLE 2-2. RELATIVE TOLERANCE OF CROP PLANTS TO SALT CONSTITUENTS IN THE
SOIL SOLUTION⁷⁴

(Arranged in order of decreasing tolerance)

High salt tolerance	Medium salt tolerance	Low salt tolerance
<i>Field crops</i>		
Barley (grain)	Rye (grain)	Field beans
Sugar beet	Wheat (grain)	
Rape	Oats (grain)	
Cotton	Rice	
	Sorghum (grain)	
	Corn (field)	
	Flax	
	Sunflower	
	Castorbeans	
<i>Vegetable crops</i>		
Garden beets	Tomato	Radish
Kale	Broccoli	Celery
Asparagus	Cabbage	Green beans
Spinach	Bell pepper	
	Cauliflower	
	Lettuce	
	Sweet corn	
	Potatoes (White Rose)	
	Carrot	
	Onion	
	Peas	
	Squash	
	Cucumber	
<i>Forage crops</i>		
Alkali sacation	White sweetclover	White Dutch clover
Saltgrass	Yellow sweetclover	Meadow foxtail
Nuttall alkaligrass	Perennial ryegrass	Alsike clover
Bermuda grass	Mountain brome	Red clover
Rhodes grass	Strawberry clover	Ladino clover
Rescue grass	Dallis grass	Burnet
Canada wildrye	Sudan grass	
Western wheatgrass	Hubam clover	
Barley (hay)	Alfalfa (California common)	
Birdsfoot trefoil	Tall fescue	
	Rye (hay)	
	Wheat (hay)	
	Oats (hay)	
	Orchardgrass	
	Blue grama	
	Meadow fescue	
	Reed canary	
	Big trefoil	
	Smooth brome	
	Tall meadow oatgrass	
	Cicer milkvetch	
	Sourclover	
	Sickle milkvetch	

TABLE 2-2—Continued

High salt tolerance	Medium salt tolerance	Low salt tolerance
	<i>Fruit crops</i>	
Date palm	Pomegranate	Pear
	Fig	Apple
	Olive	Orange
	Grape	Grapefruit
	Cantaloup	Prune
		Plum
		Almond
		Apricot
		Peach
		Strawberry
		Lemon
		Avocado

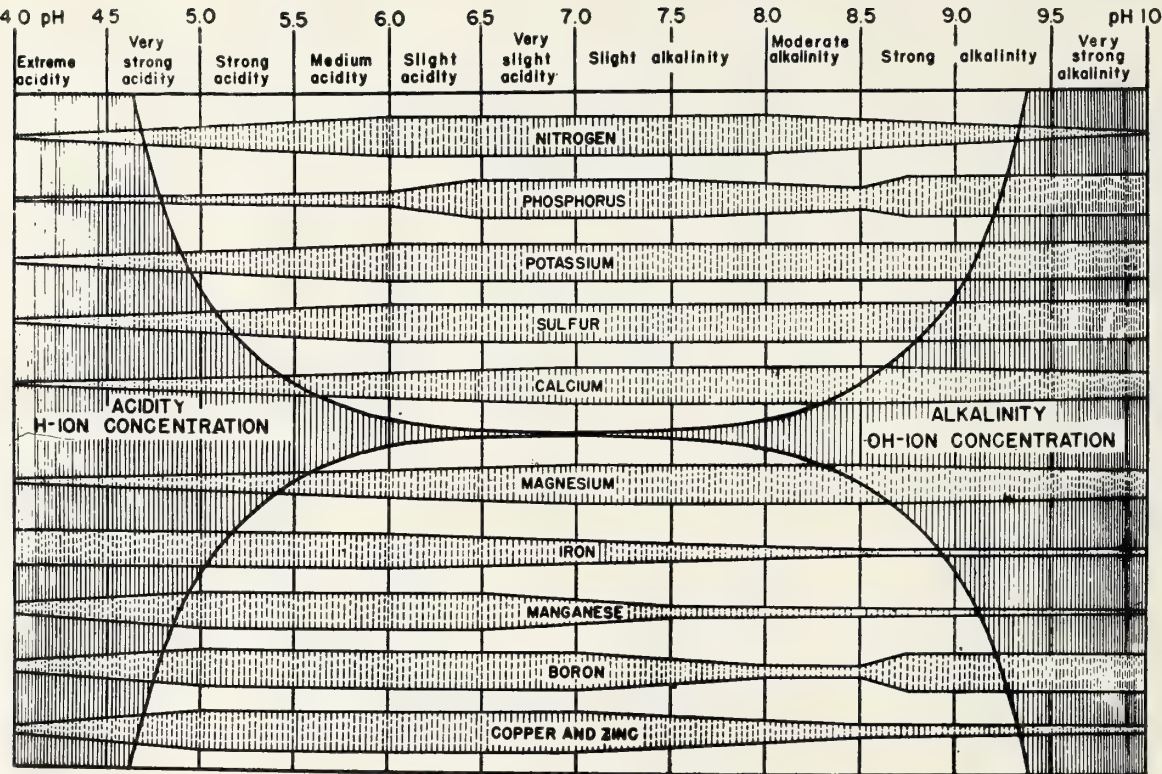


Figure 2-5. The availability of plant nutrients in relation to soil reaction¹⁰⁰. The width of the bands indicate the relative availability of the nutrients. (Courtesy of E. Truog, Wis. Agr. Exper. Sta.)

with increasing acidity the nutrient elements existing as exchangeable cations become replaced by hydrogen. On the alkaline side, some of the nutrient elements become much less soluble and available.

The favorable pH values are closely linked with the activities of soil microorganisms, particularly as related to the availability and fixation of nitrogen (see Chapter 3).

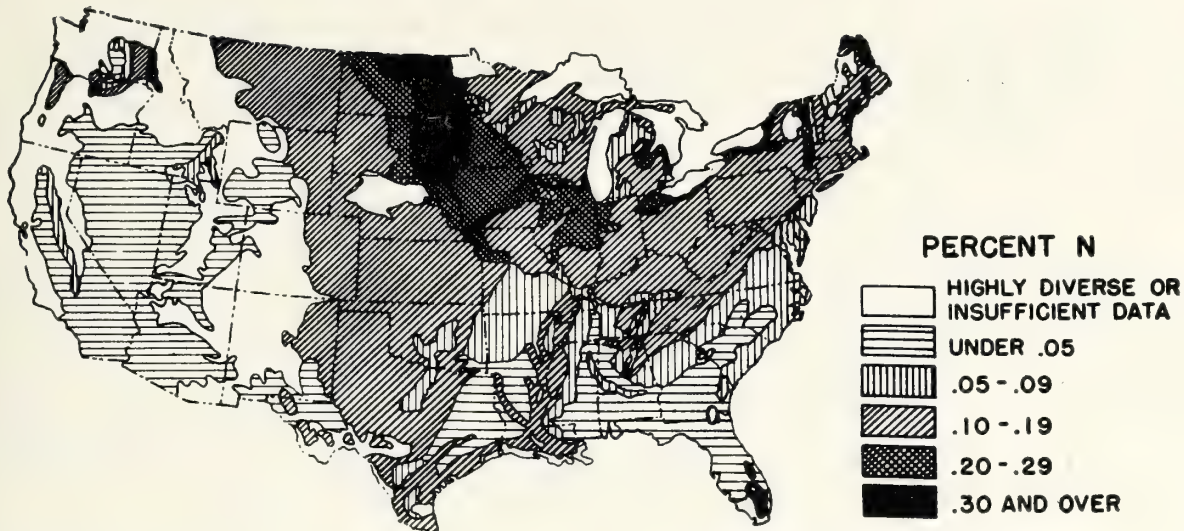


Figure 2-6. Soil nitrogen map of the United States⁶⁴ showing nitrogen in surface foot of soil. (Courtesy of K. D. Jacob, USDA)

NITROGEN

About 75.5 per cent by weight of the atmosphere consists of nitrogen³³. In its free state, nitrogen is a colorless, odorless, inert gas. The total weight of nitrogen in the air over an acre of land is about 35,000 tons. Little, if any, nitrogen is present in rocks and minerals.

Soil Nitrogen Supplies

Total nitrogen supplies in soils are small ranging from about 2,000 to 16,000 pounds per acre in the surface 6 inches of soil⁸³. The total nitrogen content of most of the soils in the United States (Figure 2-6), except for the Prairie and Chernozem soils, is less than 3,000 pounds in the surface acre layer. Concentration of nitrogen in the surface soil of forests may approach that of soils under grass. Lunt⁴⁸ found 0.215 per cent nitrogen under forest conditions while Rost *et al.*⁷⁸ report an average of 0.266 per cent for soils developed under grass. In the latter soils, the surface soil is much thicker and for this reason contains more total nitrogen.

Most of the soil's nitrogen supply exists in organic forms that cannot be utilized by plants. These organic compounds are converted by soil micro-organisms into inorganic ammonium and nitrate ions that are more soluble and more readily available to plants through the following stages:

Organic N → ammonia → nitrite → nitrate (see Chapter 3).

The amount of organic matter in soils is related to the nitrogen supply at about a ratio of 20 to 1. Most soils (on an oven-dry basis) contain about 3 to 4 per cent organic matter although dune sands contain only a fraction of a per cent and peats as much as 80 per cent.

TABLE 2-3. A COMPARISON OF THE AVERAGE ANNUAL LOSS OF NUTRIENTS BY DRAINAGE FROM A REPRESENTATIVE HUMID-REGION SILT LOAM, CROPPED TO A STANDARD ROTATION, WITH THE NUTRIENTS REMOVED BY AN AVERAGE ROTATION CROP

Losses	Pounds per acre annually					
	N	P ₂ O ₅	K ₂ O	CaO	MgO	SO ₃
Leached from a representative silt loam	5	Trace	20	125	30	25
Removed by average rotation crop.....	75	30	60	35	25	25

Reprinted by permission of H. O. Buckman and N. C. Brady from "The Nature and Properties of Soils," The MacMillan Co., N. Y., 1952.

TABLE 2-4. AVERAGE ANNUAL LOSS OF PLANT NUTRIENTS BY CROPPING AND EROSION IN THE UNITED STATES⁴⁷
(Pounds per acre)

Losses	N	P	K	Ca	Mg	S
Removed in crops.....	25.1	3.8	17.3	6.0	2.8	2.8
Lost by erosion.....	24.2	10.6	141.1	152.0	73.0	6.1

Losses of Nitrogen in Soils

Losses of nitrogen by leaching as measured by lysimeters under various soil and cropping conditions show wide variation^{15, 38, 40, 41, 45}. Lyon *et al.*⁴⁹ have made comparisons of leaching and crop removal losses (Table 2-3). Lipman and Conybeare⁴⁷ estimated losses of nitrogen by erosion and cropping in 1930 (Table 2-4). More nitrogen is removed by crops (Tables 2-4, 2-5) than by erosion or leaching. Because of low supplies of nitrogen in most soils and large losses through erosion, leaching and crop removal, nitrogen deficiency has become one of the most important agricultural problems in the world.

Many soils were originally moderately well supplied with nitrogen and therefore produced good yields during the early years of cultivation. Under cultivation a new set of conditions are established, and unless applications of barnyard manure or commercial fertilizers are made, levels of nitrogen and organic matter decrease. This decline is gradual, being most rapid during the first few years of cultivation (Figure 2-7). Indications are that the final level is dependent on the region involved, the cropping system used, and the soil treatment applied.

Additions of Nitrogen to Soils

Rain water contains dissolved nitrogen oxides and ammonia, adding 5 to 7 pounds of nitrogen per acre annually to the soil⁸³. Another source of nitrogen is the various microorganisms in the soil which can transform

TABLE 2-5. AVERAGE AMOUNTS OF NUTRIENTS REMOVED BY CROPS⁷⁶

Crop	Yield	Part of crop	N (lb)	P ₂ O ₅ (lb)	K ₂ O (lb)	Total
Cotton	500 lb	Lint }				
	1,000 lb	Seed }	38	18	14	70
	1,500 lb	Burrs, leaves, stalks	27	7	36	70
		Total	65	25	50	140
Tobacco	1,500 lb	Leaves	55	10	80	145
		Stalks	25	10	35	70
		Total	80	20	115	215
Corn	60 bu 2 tons	Grain	57	23	15	95
		Stover	38	12	55	105
		Total	95	35	70	200
Wheat	30 bu 1.25 tons	Grain	35	16	9	60
		Straw	15	4	21	40
		Total	50	20	30	100
Oats	50 bu 1.25 tons	Grain	35	15	10	60
		Straw	15	5	35	55
		Total	50	20	45	115
Barley	40 bu 1 ton	Grain	35	15	10	60
		Straw	15	5	30	50
		Total	50	20	40	110
Potatoes	300 bu	Tubers	65	25	115	205
		Tops	60	10	55	125
		Total	125	35	170	330
Sweet potatoes	300 bu	Roots	45	15	75	135
		Vines	30	5	40	75
		Total	75	20	115	210
Sugar beets	15 tons	Roots	55	22	53	130
		Tops	60	23	92	175
		Total	115	45	145	305

TABLE 2-5—Continued

Crop	Yield	Part of crop	N (lb)	P ₂ O ₅ (lb)	K ₂ O (lb)	Total
Tomatoes	10 tons	Fruit	60	20	80	160
		Vines	40	15	95	150
		Total	100	35	175	310
Cabbage	15 tons	All	100	25	100	225
Celery	350 crates	All	80	65	235	380
Spinach	9 tons or 1,000 bu	All	90	30	45	165
Apples	400 bu	Fruit	20	7	30	57
		Leaves, wood	10	3	5	18
		Total	30	10	35	75
Peaches	500 bu	Fruit	30	15	55	100
		Leaves, wood	55	10	45	110
		Total	85	25	100	210
Grapes	4 tons	Fruit	10	6	20	36
		Leaves, canes	15	4	15	34
		Total	25	10	35	70
Oranges	600 boxes	Fruit	65	23	105	193
		Leaves, wood	25	7	25	57
		Total	90	30	130	250
Soybeans	25 bu 1.25 tons	Grain	110	35	40	185
		Straw	15	5	20	40
		Total	125	40	60	225
Peanuts	1 ton 3 tons	Nuts	60	10	10	80
		Vines	25	5	40	70
		Total	85	15	50	150
Pea beans	30 bu	Grain	73	23	24	120
		Straw	22	7	31	60
		Total	95	30	55	180
Alfalfa	3 tons	All	140	35	135	310
Sweet clover	5 tons	All	185	45	165	395
Red clover	2 tons	All	80	20	70	170
Lespedeza	3 tons	All	130	30	70	230
Cow peas	2 tons	All	125	25	90	240
Timothy	1.5 tons	All	40	15	45	100

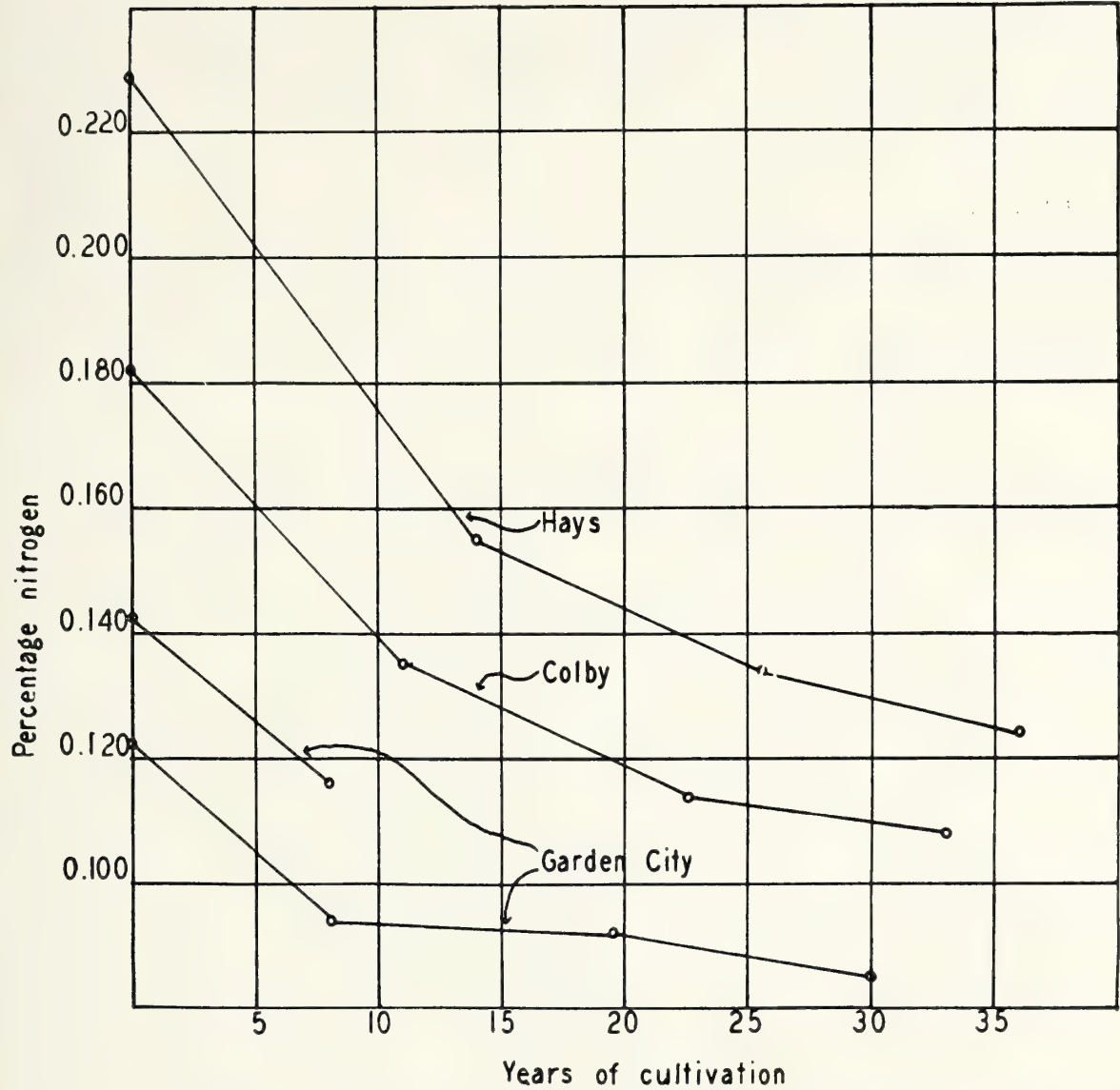


Figure 2-7. Effect of cultivation on soil nitrogen content in Kansas⁵⁶. (Courtesy of H. E. Myers, Kansas Agr. Expr. Sta.)

elemental nitrogen from the air into fixed-nitrogen compounds essential to plants (see Chapter 3). From 25 to 80 pounds per acre of nitrogen annually are added by these organisms⁸³.

Farm manures contain various amounts of nitrogen as shown in Table 4-2 (p. 91). Because about one-half of the total manure produced is dropped on pastures and uncultivated ground, and because the manures handled in barnyards loses nitrogen through leaching, fermentation, drying, and during application to fields, only about a quarter to a third of the great nitrogen potential of manure is actually realized⁸⁰.

Large quantities of nitrogen in the form of commercial fertilizers are added to the soil each year to partly counterbalance losses due to leaching, erosion and crop removal. Table 2-6 gives the average amounts of nitrogen applied per acre in 1949 in the various regions in the United States. These amounts vary because of the type of agriculture in the respective region

TABLE 2-6. COMPARISON OF FERTILIZER USE BY REGIONS* IN THE UNITED STATES

Region	N (lb/A)	P ₂ O ₅ (lb/A)	K ₂ O (lb/A)	CaO (lb/A)	Planted area (000 acres)
Northeast.....	8	20	13	251	32,800
North Central.....	2	8	4	419	230,824
Southern.....	4	9	4	52	255,726
Western.....	10	6	8	†	41,817
United States.....	4	9	5	192	516,167

* Current use in 1949, National Soil and Fertilizer Research Committee²⁵.

† No data available.

and the natural fertility of the soil. In the Northeast, for example, intensive crops such as tobacco, truck crops, and potatoes are grown. As much as 200 pounds of nitrogen, 120 pounds of phosphoric acid, and 200 pounds of potash per acre are applied to tobacco grown on sandy soils in the Connecticut Valley⁹¹. The uses and responses from crops of various kinds of nitrogen applied to soils has been reviewed by Andrews².

Analyses show that many of our soils are lower in nitrogen and organic matter than they were under virgin conditions^{56, 93}. Ensminger and Pearson²⁹ have summarized the trends for the Southeast, Midwest, Great Plains and irrigated regions. For the United States (1949) as a whole, about twice as much nitrogen is removed by crops as is added by fertilizers and manures. In a recent study in New England⁹³, about a third more nitrogen is being applied to the agricultural soils than is being removed, if a balance sheet of input versus output is drawn. The soils in this area were low in nitrogen originally and large amounts have been added in an intensive agriculture. In the North Central region (Table 2-6) increased use of anhydrous ammonia and ammonium nitrate since 1949 probably has increased the soil nitrogen supply.

Availability of Different Forms of Nitrogen in Soils

Nitrogen exists in the soil largely in the form of partially decomposed organic residues containing proteins. Microorganisms gradually transform this nitrogen into ammonia compounds (see Chapter 3). Organic nitrogenous fertilizer materials and leguminous crop residues are more readily attacked due to their high protein content. Urea and cyanamid are fertilizer materials that can be rapidly hydrolyzed to produce ammonia compounds, while nitrogen in ammonia form is directly supplied in fertilizers containing sulfate of ammonia, ammoniated phosphates, or ammonium nitrate.

Nitrogen in ammonium compounds under certain conditions may be utilized as such by many plants, especially during their early growth. Under normal field conditions only small amounts are present due to the rapid change of ammonia to nitrites and nitrates by bacterial activity. Therefore, only a few weeks after fertilizer applications supplying ammonia

have been made, little or no ammonia nitrogen and no nitrite can be identified by chemical tests. Except for a short period after such fertilizer treatment, a substantial ammonia test is an indication of unfavorable conditions for nitrification, such as high acidity, excessive or deficient moisture supply, or other disorders.

Nitrites are rarely found except as a temporary condition occasionally resulting from a heavy nitrogenous fertilizer treatment which was not well mixed into the soil, especially under poor soil aeration resulting from excess moisture. Nitrite tests in more than trace amounts should be considered as harmful.

Nitrate nitrogen, whether formed in the soil through nitrification of ammonia derived from organic residues and fertilizer materials, or directly supplied in the fertilizer, (viz., nitrate of soda), is rapidly assimilated by the roots of living plants and may be readily lost from the soil by the action of percolating water from heavy rains. Rapidly growing annual crops require a large reserve during the period of most active growth. Perennial crops with extensive root systems, such as sod grasses, shrubs and trees, take up nitrogen through a much longer period of the year.

Low amounts of nitrates are to be expected at the end of a cropping period, during winter and early spring, and after a period of heavy rainfall. Under such conditions, when all other factors are favorable, the absence of nitrates may not necessarily indicate poor availability of soil nitrogen, although the crop is apt to respond to the addition of a readily available nitrogenous fertilizer.

Nitrogen Interaction with Soil

Continued use of nitrogenous fertilizers result in changes in soil reaction⁶⁵. Ammonium sulfate, ammonium nitrate, anhydrous ammonia, and urea have marked acidulating effects on the soil while others like calcium cyanamide, sodium nitrate, calcium nitrate, etc., decrease soil acidity (Table 2-7). The nitrate form of nitrogen is readily leached from the soil, the ammonium forms are held rather tenaciously, and organic forms are practically immobile (Table 2-7). Sodium nitrate serves as a good example of a fertilizer having beneficial and deleterious effects⁶. The acidic nitrate ion is taken up by crops to a greater extent than the basic sodium ion. The excess sodium ions replaces hydrogen ions, and, as a result the availability of soil phosphate is increased. In alkaline soils, with long use the sodium may accumulate and disperse the soil colloids, developing a bad physical condition. For some plants, however, sodium has value as a nutrient.

Ammonia nitrogen in fertilizers undergoes nitrification in the soil to form the acidic nitrate ion producing increased soil acidity. This acidic nitrate

TABLE 2-7. PROPERTIES OF NITROGEN CARRIERS

Material	Percentage N*	Acidity or alkalinity†	Retention by soil‡	Condition quality§
Ammonia (anhydrous)	82	-148	Medium	Fair
Urea	46	-84	Medium	Fair
Ammonium nitrate	35	-59	Low	Fair
Ammonium chloride	26	-140	Medium	Fair
Ammonium sulfate	21	-110	Medium	Fair
Calcium cyanamide	22	+62	Medium	Good
Calcium nitrate	17	+20	Low	Poor
Sodium nitrate	16	+29	Low	Fair
Ammonium phosphate	12	-65	Medium	Good
Dried blood	10	-22	High	Good
Animal tankage	6	+10	High	Good
Cottonseed meal	6	-9	High	Good
Fish scrap	5	-8	High	Good
Tobacco stems	2	+12	High	Good

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* Commercial products may contain somewhat less than these percentages.

† In terms CaCO_3 for 100 pounds of material: - = acid, + = alkaline.

‡ Capacity of soil to retain until used by plants.

§ For fertilizer-mixing purposes.

ion neutralizes soil bases. Ammonium salts like ammonium sulfate have a double acidifying effect. The basic ammonium ion is converted by nitrification into the acidic nitrate ion. The residual acidic sulfate ion and the acidic nitrate ion both react with soil bases.

Utilization of Nitrogen by Plants

Nitrogen is essential in the growth and reproduction of plants. It is a component of chlorophyll and of protein and is a constituent of every living cell. It is found in greater quantities in young growing parts of plants than in the older tissues and is especially abundant in the leaves and seeds. The effects of nitrogen nutrition on plant life are varied and complicated^{86, 102} and may be listed as follows:

- (1) Stimulates plant growth and increases general plant vigor.
- (2) Promotes increased leaf and stem growth.
- (3) Imparts dark green color to leaves and other foliage.
- (4) Adds crispness and improved quality to leaf crops.
- (5) Promotes rapid and vigorous early growth.
- (6) Increases the protein content of food and feed crops.
- (7) Hastens maturity of plants when used in moderate amounts.
- (8) Increases yield of fruits and grains.

An adequate supply of available nitrogen in soil is one of the most important factors in soil fertility and crop production. A deficiency may stunt

plant growth, decrease vigor and reduce yields. Hunger signs of crops for nitrogen have been published in color^{9, 22, 103}. Typical symptoms of nitrogen deficiency^{98, 102} are:

- (1) Loss of normal dark green color.
- (2) Pale, yellowish leaves.
- (3) Stalks that show an uncommon amount of pink or light red color.
- (4) Lower leaves that turn yellow or orange, often fall badly and sometimes shed prematurely.
- (5) Slender stalks and branches.
- (6) Slow growth and development.
- (7) Low yields.
- (8) Poor quality in leafy crops like lettuce, etc.

Sometimes, because the effects of nitrogen on plants are so readily apparent, too much nitrogen is applied to the soil. This practice is wasteful since much of the nitrogen is soon leached from the soil and large amounts produce harmful effects on certain crops. Such detrimental effects may be as follows:

- (1) Quality of certain crops, such as grains, fruits and tobacco, may be reduced.
- (2) Maturity may be delayed by encouraging continued growing of the plant beyond its normal growth period.
- (3) Yields may be reduced because excess vegetative growth may occur at the expense of seed formation.
- (4) The stems of crops like grain may be weakened, encouraging lodging.
- (5) Resistance to plant diseases may be weakened.
- (6) Stooling or tillering of cereal crops is increased.

PHOSPHORUS

Phosphorus, the eleventh most abundant element, is widely distributed in the lithosphere, making up 0.12 per cent of the earth's crust⁵⁴. The most common phosphorus-containing compound is calcium phosphate, $[\text{Ca}_3(\text{PO}_4)_2]_3 \cdot \text{CaF}_2$, occurring in the mineral apatite.

Large deposits of phosphate rock occur in the United States, principally in Florida, Tennessee, South Carolina, Arkansas, in the East and in Idaho and neighboring states in the West⁸¹. Known deposits in the United States contain 54 billion tons of phosphate rock⁵⁴. At the present rate of consumption these resources will supply our needs for 4,500 years. Deposits in the United States comprise more than one-fourth of the world's known deposits⁵¹.

Soil Phosphorus Supplies

The total phosphorus content of soils is greatly influenced by the phosphorus content of the parent material. The phosphorus (P) content of ig-



Figure 2-8. Soil phosphorus map of the United States⁶⁴ showing phosphoric acid in surface foot of soil. (Courtesy of K. D. Jacob, USDA)

neous rocks is about 0.15 per cent, limestone about 0.02 per cent, and sandstones and shales intermediate⁶. Phosphorus in soils to plow depth ranges between 0.025 to 0.125 per cent, the average being about 0.06 per cent.

The high phosphorus soils of the Bluegrass Region in Kentucky and Tennessee (Figure 2-8) are derived from phosphatic limestone⁶³. The low phosphorus soils of the Atlantic and Gulf Coastal region are derived principally from parent materials low in total phosphorus. Many of the soils in this area contain less than 500 pounds per acre in the plow layer in contrast to 1,200 to 1,500 pounds per acre for soils in the North Central states⁶⁶. On an average, the percentage of phosphorus in surface soils is only about one-half that of nitrogen and one-twentieth that of potassium.

Both inorganic and organic forms of phosphates occur in soils. The inorganic forms consist of two major groups, the calcium phosphates, and the iron and aluminum phosphates. Studies⁶⁷ show that the latter phosphates tend to accumulate in acid soils below pH 5. As the soil pH approaches neutrality, calcium ions become more abundant in the soil solution and calcium phosphates occur. In the slightly acid range some phosphates may be adsorbed on the surface of clay particles as an anion. As the pH goes above neutrality, especially in calcareous soils, complex compounds of tri-calcium phosphate with calcium hydroxide or calcium carbonate are formed.

The three main groups of organic phosphorus compounds are phytin, nucleic acid, and phospholipids. Approximately half of the organic soil phosphorus comes from the first two groups. The amounts of organic phosphorus in soils vary widely, ranging from 2.6 per cent of the total soil P in an Orangeburg sandy loam in Mississippi to 75 per cent for a peat from Finland¹⁶.

Losses of Phosphorus from Soils

Little, if any, phosphorus is removed from soils by leaching action (Table 2-3). Removal from the land is principally by harvesting of crops or by soil erosion (Tables 2-3, 2-4 and 2-5). The low leaching losses are explained by the low water-solubility of the soil phosphate compounds; the soil solution of most soils contains less than 0.1 ppm of inorganic phosphorus⁶⁹. On hilly topography, losses by erosion may be much greater than by crop removal⁶⁰. The fine particles of soil are lost by erosion and it is in these particles that phosphorus is most abundant. Both the percentage and the solubility of the phosphorus in eroded soil material are higher than in the soil *per se*⁷⁵. For these reasons eroded soils are usually deficient in phosphorus.

Addition of Phosphorus to Soils

Farm manures applied to soils supply phosphorus (see Chapter 4). From 35 to 140 pounds per acre of P_2O_5 may be supplied by manure applications⁶³.

More phosphorus is applied as a nutrient to soils than any other fertilizer. In 1952-53, 2,270,750 tons of P_2O_5 were applied compared with 1,637,056 tons of nitrogen and 1,740,210 tons of K_2O ⁸². Because only part of the phosphorus applied is recovered in crops and little is lost by leaching, the phosphorus content of soils rise, especially in soils to which large applications are made¹. In soils in Maine cropped to potatoes and heavily fertilized, the cultivated soils had 217 pounds per acre of available P_2O_5 compared with 34 pounds per acre for soils in forests⁹³. Parker⁶³ has prepared an estimate of the increase of phosphorus in soils in relation to the amount added by fertilization to that removed by cropping (Table 2-8).

Availability of Phosphorus in Soils

Phosphatic fertilizers differ from those containing nitrogen and potassium in that only a relatively small proportion of the applied phosphate is taken

TABLE 2-8. ESTIMATED PER CENT OF PHOSPHORUS REMOVED IN HARVESTED CROPS THAT IS REPLACED BY FERTILIZER AND MANURE⁶³

Region	1920	1947	1955
New England.....	817	365	408
Middle Atlantic.....	281	350	470
South Atlantic.....	683	544	677
East North Central.....	142	216	366
East South Central.....	127	266	403
West North Central.....	41	51	105
West South Central.....	19	65	174
Mountain.....	128	74	108
Pacific.....	55	91	145
Continental U. S.....	124	153	246

up by the crop. Probably only about 10 to 25 per cent is recovered in the first crop, and an additional 10 per cent is recovered in succeeding crops, but it is never completely removed from the soil. As much as 31 per cent has been recovered in hay over a period of four years⁷⁹. Where heavy applications of phosphate are made over a period of years there is a considerable accumulation of total and available phosphorus in the soil^{1, 93}.

The reason for the low uptake of phosphorus is that it loses its solubility soon after contact with the soil, a process known as fixation. This loss of solubility may be due to several factors⁵⁸. The organic content of the soil, the soil pH, the amount of soluble calcium and magnesium, the quantity of reactive iron, aluminum and manganese, the amount and chemical nature of the clay colloids, activities of microorganisms, the structure and aeration of the soil are all important factors affecting the phosphate-fixing capacity of soils. Because of differences in the degree of these various factors, soils vary greatly in their capacity to fix phosphates.

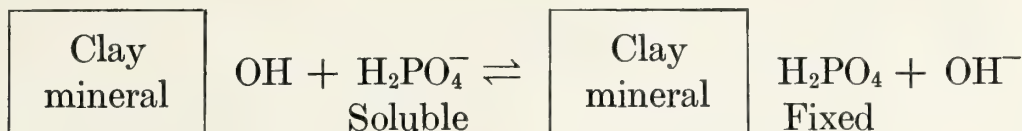
There is a tendency toward equilibrium between phosphorus in solution and the amount of fixed inorganic phosphorus. The change from the fixed form to available phosphorus is quite slow compared with the rate of fixation⁹⁶. The amount of phosphorus in solution at any one time is not so important as the ability of the soil to maintain the level of soluble phosphorus while crops are growing. The amount of phosphorus in the soil solution may often be less than 0.1 pound per acre, especially while a crop is growing.

The effect of soil pH on nutrient availability has been discussed above. The kind of phosphate ion in soils varies with the pH of the soil solution⁴⁹. Under alkaline conditions, the PO_4 ion is most common, and under acid conditions, the H_2PO_4 ion dominates. At slight to moderate acidity, both HPO_4 and H_2PO_4 ions prevail. These latter ions are thought to be more available to plants than the PO_4 ion.

The fixation of phosphorus in soils is beneficial in that phosphorus is not leached out of the soil. Fixation is detrimental in that the phosphorus may not be readily available to crops. Under acid conditions (Figure 2-5) soluble iron, aluminum and manganese react with H_2PO_4 ions, making the phosphorus insoluble and unavailable to plants. Swenson *et al.*⁹⁴ have shown that phosphate may be precipitated by iron and aluminum as $\text{Fe}(\text{OH})_2\text{H}_2\text{PO}_4$ and $\text{Al}(\text{OH})_2\text{H}_2\text{PO}_4$. The H_2PO_4 ion reacts also with the surface of insoluble hydrous oxides of iron, aluminum, and manganese such as limonite and goethite.

Clay minerals like kaolinite, montmorillonite, and illite fix phosphorus. Apparently, H_2PO_4 ions replace OH, fixing the phosphorus. Lyon *et al.*⁴⁹

show this fixation to be a reversible one as follows:



Such a reaction represents a process known as *anion exchange* since one anion is exchanged for another.

Organic compounds form complexes with iron and aluminum, preventing the precipitation of phosphorus by iron and aluminum⁵⁷. Organic matter on decomposition forms organic acids which dissolve fixed inorganic phosphates. The organic acids also form complexes with iron and aluminum, reducing phosphorus fixation⁹⁴.

The processes by which fixed phosphorus in the soil becomes available for plant use are not well understood. Because various kinds of organic and inorganic acids, such as H_2CO_3 , H_2SO_3 , and HNO_2 are produced in the soil, it is assumed they have a part in making fixed phosphorus more available. The following equation⁵⁸ illustrates how such a reaction might proceed; tricalcium phosphate and carbonic acid are used.



The application of lime causes a gradual change of the phosphates to calcium phosphates. Thus the addition of any organic material to the soil which increases the production of carbonic, nitrous, or sulfurous acid favors the availability of phosphates. The subject is reviewed in detail by Dean²⁷, Weld¹⁰⁴ and Pierre *et al.*⁶⁸.

Utilization of Phosphorus by Plants

Phosphorus, like nitrogen, is closely concerned with the vital growth processes in plants. It is a constituent of every living cell and therefore must be plentiful for rapid growth. This relation is reflected in the high phosphate content of seeds. It is necessary for cellular respiration and in the metabolism of starch, proteins, and fats. The first step in the oxidation of carbohydrates is the combining of simple sugars with phosphate. Phosphorus is usually the first element that becomes deficient after a soil is brought under cultivation. Because the total supply of phosphorus in soils is relatively small, the available supply usually falls short of crop requirements.

The effects of phosphorus on plant growth^{59, 86, 103} may be summarized as follows:

- (1) Aids the plant in taking up potassium.
- (2) Tends to counteract the effects of excess nitrogen.

(3) Stimulates early root formation and growth, particularly of the lateral and fibrous roots.

(4) Hastens the maturity of crops.

(5) Stimulates blooming of plants and aids seed formation.

(6) Winter hardiness is increased in hay and fall-seeded grain crops by phosphorus.

(7) Improves the quality of certain crops.

(8) Increases the resistance of some plants to disease.

(9) Strengthens the straw of cereals, decreasing lodging, decreasing the ratio of straw to grain, and increases total yield.

Low available phosphorus in soils means not only delayed maturity and poor plant growth but a low phosphorus content in the plant. Hunger signs of phosphorus in plants have been published in detail in color photographs^{9, 22, 103}. Symptoms of phosphorus deficiency are:

(1) Slow plant growth; plants are small and spindley and often woody or brittle.

(2) An undeveloped root system.

(3) Poor setting of flowers and fruits when accompanied by fair vegetative growth.

(4) Lodging of cereal crops.

(5) Purple-colored leaves.

(6) Large proportion of undersized flowers, fruits, vegetables and seeds. The seeds may be shriveled, light in weight and have poor viability.

Control of Phosphorus Availability in Cropping

Because the efficiency of phosphorus utilization by plants is very low and the soil has a marked ability to fix applied phosphorus in forms which are unavailable to plants, not much progress has been made in increasing phosphorus availability. The best ways in which to increase the availability of phosphorus are: (1) keeping the soil between a pH of 6.0 to 7.0 by liming; (2) banding or row application; (3) pelleting the fertilizer to reduce contact with the soil; and (4) maintenance or improvement of the supply of soil organic matter. Phosphorus is more readily available to plants as soil moisture increases up to the optimum. The reverted phosphorus is not lost entirely but becomes slowly available to plants over the years. In soils heavily phosphated for a number of years application of phosphate may be reduced.

Phosphorus Fertilizers and Their Use

Among the kinds of phosphorus fertilizers given in Chapter 4, superphosphate is the most important source. About two-thirds of the phosphoric acid in fertilizers in the United States is supplied by superphosphate (see

Table 4-15, p. 118). Most of the phosphoric acid of superphosphate is water-soluble and is immediately available but is quickly fixed in soils as discussed above. High-analysis or concentrated superphosphate, containing from 30 to 50 per cent phosphoric acid (see Chapter 4) has an advantage because of its high content of phosphoric acid for less than half as much is required as the normal grades. This means an economy in transportation and handling charges. A disadvantage of concentrated superphosphate is its lack of calcium sulfate compared with ordinary superphosphate. The calcium and sulfate can be supplied cheaper in the form of limestone or gypsum.

Ammonium phosphates are another source of high-analysis phosphate fertilizers (see Chapter 4). Greater savings in freight and handling costs are realized than for concentrated superphosphates because of its higher concentration. There is some indication that ammoniated phosphates have a greater ability to penetrate the soil than do the concentrated superphosphates. Ammoniated phosphates are increasing in use, especially in the Western states and in the West North Central states⁸².

Rock phosphate, a finely pulverized phosphate rock, is used as a phosphorus fertilizer principally on soils high in organic matter. It is the least available of the phosphatic fertilizers. Because of its bulk, long hauls from the source of supply make this fertilizer expensive.

A choice from among the various phosphatic fertilizers depends largely on the soils, climate, cropping conditions and the prices at which they may be purchased. Those discussed above are used most extensively in the United States. On a smaller quantity basis, bone meal is preferred by gardeners and florists because of its slow availability and resulting protection from fertilizer "burn," especially if large quantities are applied. Response of crops and soils under various soil and cropping conditions to phosphatic fertilizers is given by Andrews² and Thompson⁹⁶.

The various phosphorus compounds present in phosphatic fertilizers are evaluated for sale purposes on the basis of their solubility⁴⁶ as (a) water soluble, (b) citrate-soluble and (c) citrate-insoluble. The availability of phosphorus applied to soils cannot be determined from such solubility ratings. The availability of phosphorus in soils has been discussed above.

POTASSIUM

Potassium is widely distributed in the earth's crust and occurs naturally in soils as a constituent of silicate minerals such as feldspars (chiefly orthoclase and microcline) and micas. Oceanic waters contain only about 0.04 per cent of potassium in contrast with about 2.45 per cent in the earth's crust²⁶.

In the United States some of the more common potash-bearing minerals

and rocks⁵⁸ include alunite, mica, green sand (glaucinite), and potash shales, ranging from 3 to 10 per cent K_2O content. Because the potash in these minerals is insoluble they are not extensively used as fertilizers. Large deposits of soluble potassium compounds suitable for fertilizer purposes are found in only a few places, principally in Germany, France, and the United States with some in Spain, Russia, Israel, and Chile. In the United States, chloride and sulfate of potassium are obtained from saline lakes and underground deposits, principally in the Southwest⁷⁷. In early colonial times potash in the form of wood ashes was used. When the potash deposits in Germany were developed in 1859, importation of potash salts displaced wood ashes.

Dolbear²⁸ shows over 100 million tons K_2O in easily workable saline lake deposits in operation today in the United States, nearly two and a half times more in underground deposits, and about eight times more in insoluble mineral reserves. The latter two reserves represent materials which may be used if needed although further technical information is required before they can be made available economically. Only about 1 per cent of the world's estimated supplies of soluble potassium salts is found in the United States⁶. Additional information on potash resources in the United States is given by Reed⁷².

Soil Potassium Supplies

Unlike nitrogen and phosphorus, the amount of total potassium found in soils is comparatively high (Figures 2-6, 2-8, and 2-9). The amount of potash occurring in soils naturally is influenced by the amount contained in the rocks from which the soils are derived. In general, it is high in areas having soils produced from rocks weathered rather recently, as in glaciated and mountainous areas, and in the drier parts of the United States (Figure 2-9).



Figure 2-9. Potash content of the soils of the United States⁶⁴ in surface foot of soil. (Courtesy of K. D. Jacob, USDA)

Potassium (K_2O) ranges from about 0.15 per cent in sands to 4 per cent or more in clay soils. As an average, soils contain about 2 per cent K_2O or about 40,000 pounds per acre to plow depth²⁶. Potassium occurs in soils as (a) a constituent of certain primary minerals such as feldspars and micas, (b) associated with soil clays in readily exchangeable forms, (c) associated with secondary soil clays as nonreplaceable potassium, and (d) as water-soluble salts. Of the clay minerals, the illite group is considered to be the only one having a substantial potassium content⁷³, often containing more than 4 per cent.

Losses of Soil Potassium

The amount of potassium lost by leaching is much greater than the amount of phosphorus (Table 2-3). Because of the larger supplies in the soil, leaching losses of potassium, while appreciable, probably are not important except in soils low in potassium. Loss of potash from leaching varies with the soil, climate, cropping and soil management systems. The lower leaching losses usually occur in arid regions and in the finer-textured soils with high clay content and high absorptive capacity and the higher losses in the coarser-textured sandy soils. It is usually considered that in most soils potassium is intermediate in its loss by leaching, lower than nitrogen and calcium, about the same as magnesium, and higher than phosphorus⁷⁷.

In contrast with nitrogen (Tables 2-3 and 2-4), more potassium is lost by erosion than by crop removal. Average amounts of potassium contained in harvested crops are given in Table 2-5. Potassium removal by crops is high, often three to four times that of phosphorus and about the same as nitrogen. Plants tend to absorb more potassium than they need if large quantities of soluble potassium are available in the soil. This tendency of plants is called luxury consumption since the excess potassium does not increase crop yields. On a practical basis this is avoided by light applications of potassium fertilizers at frequent intervals instead of all at once. For example, for some crops which are heavy feeders of potash, such as alfalfa, potash is applied to the soil two or three times during the growing season instead of applying all of it at the beginning of the season.

Additions of Potassium

Farm manures contain various amounts of potassium as shown in Chapter 4. For various reasons, as discussed under Nitrogen, only about a quarter to a third of the potassium in manures actually reaches the soil. Even so, barnyard manure is the largest single source of potash added to the soil⁷⁷.

More potash is applied to soils in commercial fertilizers than nitrogen, but less than phosphorus⁸² for the United States as a whole. The smallest amount is used in the Western region where the potash content of the soil

is high (Figure 2-9). The amount applied varies with the crop since some crops like potatoes and tobacco require high amounts for maximum yields and quality. Lipman and Conybeare⁴⁷ estimated that about 1.8 million tons of potash (K_2O) are added annually to soils in the United States by rainfall (dust).

Availability in Soils

Potassium-bearing minerals are resistant to weathering, and in spite of the high content of potassium in soils, the rate at which potassium is made available to crops in many soils is often too slow to meet requirements for maximum yields. This is especially true on soils after long periods of cropping, or on soils producing crops like tobacco and potatoes with high potash requirements. The supply of available potassium is often supplemented by additions of fertilizers and manures.

Forms of potassium in soils can be grouped on the basis of their availability to plants⁴⁹ into (a) relatively unavailable, (b) readily available, and (c) slowly available. Most of the potassium in soils (90 to 98 per cent of total K) contained in soil minerals like feldspar and mica is in the relatively unavailable forms. Solvents like carbonated water make small amounts of this form of potassium available to plants during the growing season.

About 1 to 2 per cent of the total potassium in soils is in the readily available form which exists as (a) potassium in the soil solution and (b) exchangeable potassium adsorbed on the surface of soil colloids. Potassium in the soil solution form is taken up by plants more readily than the exchangeable form and is likewise more easily leached from the soil.

As potassium is added to the soil in the form of a fertilizer, fixation of the element by soil colloids may occur. The amount fixed is usually greatest in soils with the highest colloid content, as in clays and clay loams, and least in the sandy coarse-textured soils as in sandy loams. In general, potassium is not fixed as readily as phosphates. This slowly available or fixed potassium (1 to 10 per cent of total K) is not exchangeable and is called non-exchangeable potassium. Neither is it readily available to plants. Fixed potassium occupies an intermediate position between the relatively unavailable and the exchangeable potassium. An equilibrium exists with the available forms of potassium which may be shown as follows:



As plants grow, the soil solution potassium is taken up first, then potassium in the exchangeable form from the soil moves into the soil solution restoring the equilibrium of potassium in the soil. When potash fertilizers are added to the soil, the reverse action takes place. Much of the potassium becomes soluble in the soil and is attached to the soil colloids. Thus the equilibrium shifts to the left and some exchangeable potassium is converted

to the nonexchangeable form. This adjustment is of special importance in the management of soils high in illite for potassium in this form is not subject to leaching, becoming available to plants again when the adjustment is to the right.

Factors Affecting Potassium Fixation and Release

Soil conditions such as (a) kind of clay colloids, (b) wetting and drying, (c) freezing and thawing, (d) excess lime and (e) soil aeration influence the amounts of potassium fixed in soils. The kaolinite or 1:1 type of colloids (see Chapter 1) fix little potassium; montmorillonite and illite or the 2:1 type colloids fix potassium readily and in large amounts⁸⁷. Apparently, this fixation occurs only on drying for the potassium is trapped between the structural units of the colloid. On wetting, some of the potassium is slowly released. In micaceous minerals like illite under wet conditions, potassium apparently gets into the interior of the structural units of the colloid. Alternate freezing and thawing has been found to release potash³⁰. Soils high in lime in humid regions contain less exchangeable potassium than soils low in lime⁸⁸. Furthermore, high-lime soils have a greater capacity to fix potassium in nonexchangeable form than neutral or acid soils.

Soils with poor structure usually have decreased aeration and a decreased uptake of potassium by plants. A wet growing season tends to saturate soils with moisture inducing poor aeration, especially on soils which are normally poorly drained.

While potassium occurs in nearly all plant and animal tissues, it does not accumulate like phosphorus in bones or seeds, remaining essentially soluble. On return to the soil in the form of manure or plant remains, potassium is released on decay or is washed out by rains entering into the soil solution as soluble potassium. In this form it may be taken up by the plant or become exchangeable potassium, depending on the potassium equilibrium in the soil. An excellent discussion on soil potassium and its relation to plant growth is given by Reitemeier⁷³. Relationships of soil microorganisms to soil potassium are discussed in Chapter 3.

Utilization of Potassium by Plants

Plants differ markedly in their content of potassium (Table 2-5). The feeding power of plants for potassium is probably related to their rate of growth⁷⁷. Plants that grow slowly can probably utilize the less soluble forms of potassium to a greater extent than those that grow rapidly, since they have a longer time to absorb the potassium.

Beneficial effects of potassium on plant growth^{59, 102, 103} may be summarized as follows:

- (1) Potassium is necessary for the formation of carbohydrates, increasing the efficiency of leaves in assimilating carbon dioxide, and aids in the

formation and transfer of starch and sugar and in the development of chlorophyll. Potassium is not found in permanent organic combinations with these compounds, but it is believed essential for the production of all of them.

(2) Potassium has a marked influence on the growth and development of leaves and woody parts of stems. Larger amounts of potassium compounds are found in these plant parts than in any other.

(3) Potassium encourages the development of root systems of plants.

(4) Potassium is necessary for the normal development of the fleshy portions of fruits.

(5) Potassium is believed to be the agent associated with the maintenance of turgor in plant cells and the entrance of water into plants, thus affecting the resistance of the plant to injury from drought and frost.

(6) Potassium improves the quality and composition of plants. The weight of grain is increased and the stalk and straw of plants are made more rigid, reducing lodging. Potassium affects the quality of tobacco, improves the quality in potatoes, and increases the sugar content of sugar beets.

(7) Potassium aids in counteracting plant diseases and promotes the health and vigor of plants.

(8) Potassium tends to balance excess amounts of nitrogen in plants producing firmer plant tissues.

(9) Potassium produces a pronounced favorable effect on the growth of legumes like clover, alfalfa, beans, etc.

(10) Potassium is involved in the reduction of nitrates and in protein synthesis; the absence of sufficient potassium may cause nitrates to accumulate.

(11) Potassium is necessary for tuber development as in potatoes and in other root crops.

Symptoms showing potassium deficiencies for many important crop plants have been published in color^{9, 22, 103}. Potassium is required in large amounts during the time of most rapid growth. Sandy soils and peat and muck are usually low in potassium and need potash fertilizers for maximum yields. Potash deficiencies show up quickly on these soils. Some characteristic symptoms indicative of potassium deficiency in plants are:

(1) A yellowish mottling of the leaves, which usually begins at the tip and edges, progressing gradually toward the center and between the leaf veins. In advanced stages, the color becomes bronze to dark brown. The affected leaves usually have a dry scorched appearance commonly known as marginal leaf "firing."

(2) A lack of available potassium in the soil is likely to produce poor quality crops. Grain is often shriveled and below weight; potatoes are watery, low in starch, and poor in edible qualities; ears of corn are chaffy

and not well filled out to the tip of the cob. Tobacco has poor flavor and lacks the free-burning quality necessary for commercial use.

(3) Lodging of corn and small grains due to root rot and to weak stalks or stems.

(4) Reduced vigor and greater susceptibility to disease.

(5) "Rust" reddish brown leaves of cotton, a bronze discoloring of the leaves causing poorly developed bolls that do not open well at maturity.

(6) White or yellowish dots arranged in a crescent-like pattern around the edges of alfalfa and clover leaves.

Potassium acts as a stabilizer of nitrogen and phosphorus in plant growth²⁶. It tends to slow down the effects resulting from excessive nitrogen and to prevent the too rapid maturity often induced by too much available phosphorus.

An excess of available potassium in the soil delays crop maturity and causes softness of tissues and poor keeping quality of plant products⁸⁶. Excessive amounts of available potassium are found in greenhouse, lawn and garden soils but rarely in field soils under humid conditions.

Potash Fertilizers and Their Use

Muriate of potash (KCl) and sulfate of potash (K_2SO_4) are the most extensively used potash fertilizer materials (see Chapter 4). All the potassic fertilizers are in water-soluble forms and are easily absorbed by plants. They have little or no effect on soil pH. The muriate form is usually the cheapest. For this reason the sulfate form is usually applied only to soils producing crops of high acre value which has some special quality which raises its selling price. Tobacco growers, for example, use sulfate of potash and organic sources like cotton seed meal because of their low chlorine content. Chlorine affects the flavor and burning-quality of tobacco. In some of the sugar beet, potato, and citrus areas, the sulfate is also preferred over the muriate⁶.

Potash fertilizers are applied principally to cotton, tobacco, potatoes, sugar beets, certain cereals, hay and truck crops. These crops are all high users of potash. In 1952-53, the South Atlantic and East North Central states were the leading users of potash fertilizers⁸². An excellent review of the response of crops and soils to potassic fertilizer application under various soil conditions is given by Andrews² and Thompson⁹⁶.

CALCIUM

The average calcium content of the lithosphere has been estimated at 3.64 per cent⁶. Calcium occurs principally in limestone which has a calcium content of about 30 per cent. Dolomite is the next most common calcium-bearing rock. Gypsum, a more readily soluble mineral form of calcium, is another source of calcium occurring in quantities which can be quarried.

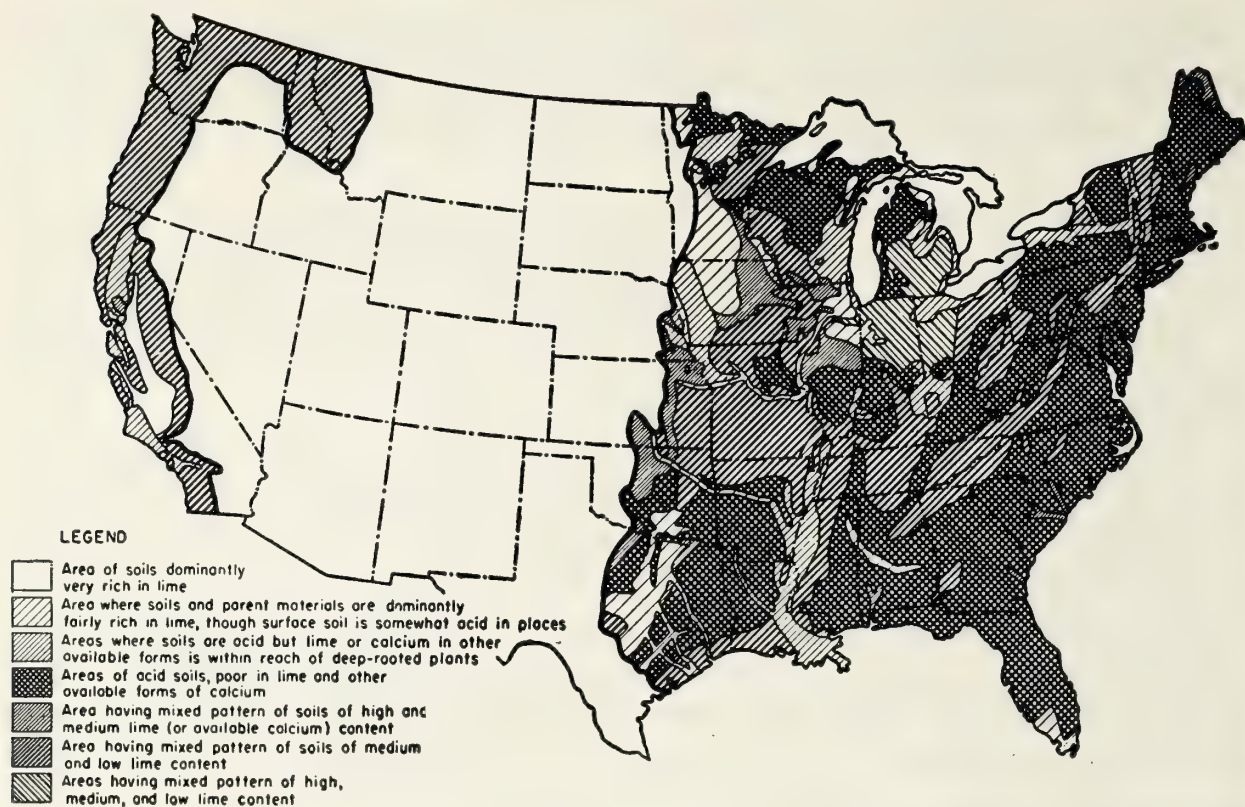


Figure 2-10. The relative lime content and acidity of the soils of the United States. (Reprinted by permission of L. M. Thompson from "Soils and Soil Fertility," McGraw-Hill Book Co., Inc., New York, 1952.)

Soil Calcium Supplies

Soils vary in CaO content, ranging from 0.10 to 5.00 per cent⁴⁹ in the plow layer. The average is about 0.60 per cent in the humid region and 1.50 per cent in the arid region or 12,000 and 30,000 pounds per acre, respectively. Calcium is readily leached out of the soil as calcium bicarbonate; therefore, in humid regions the calcium content of soils is low compared with soils in arid regions (Figure 2-10).

Anorthite, augite, hornblende, epidote, and apatite are minerals occurring in soils¹⁷ which are relatively high in calcium. Soil clays contain calcium but little is found in organic forms.

Losses of Calcium

Intensity and amount of rainfall, seasonal temperature, the chemical and physical nature of the soil, kind of crop grown, and tillage operations are all factors which influence calcium removal from the soil. Average losses by leaching, cropping, and erosion are given in Tables 2-3 and 2-4. A discussion of calcium removals from soils is given elsewhere⁹².

Additions of Calcium

Large amounts of calcium are applied to soils each year (Table 2-6), the average for the United States, including all cultivated land, being nearly

200 pounds per acre. Actually, in agricultural practice about 1 to 4 tons of agricultural limestone (or its equivalent) are applied per acre. The various kinds of liming materials used are given in Chapter 4.

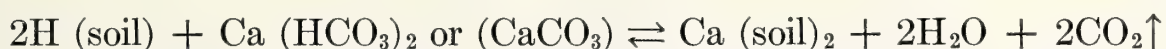
Manures (Table 4-2, p. 91) and commercial fertilizers (Table 4-14, p. 114) contain appreciable amounts of calcium. Superphosphate, for example, contains more calcium than phosphorus. The amount of calcium added to soils in manures and fertilizers is given in Table 4-18, p. 131.

Interaction of Lime with the Soil

Soil acidity usually is due to a lack of exchangeable metallic cations. Acidity can be corrected by the use of lime, which raises the pH of the soil and the level of available calcium and magnesium and lowers that of manganese, iron and aluminum. The effects of soil pH on nutrient availability to plants have been discussed above.

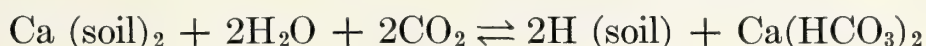
The common liming materials contain calcium and magnesium in the carbonate, oxide, or hydrate forms, as their acid-neutralizing elements⁵. Calcite, which is pure calcium carbonate, is commonly assigned a relative neutralizing value of 100. The relative neutralizing values of several pure liming materials are given in Table 2-9.

Lime, when added to the soil, undergoes chemical changes, depending on the kind of lime (see Chapter 4), the chemical nature of the soil, and the soil moisture supply. The carbonate form of lime is only slightly soluble in water. In the finely divided state it appears to displace hydrogen ions on the colloidal soil particles, thus reducing the potential acidity⁵⁸. The reactions of the carbonate in neutralizing acidity may be illustrated as follows:



As the reaction proceeds, carbon dioxide is freely evolved and the soil colloids are charged with bases.

It is apparent that calcium exists principally in two forms in the soil, as carbonates and as exchangeable calcium in association with the organic and inorganic colloids. In these forms, the bases can be changed to bicarbonates by the action of carbonic acid. In the bicarbonate form they may be readily leached from the soils in humid regions. These reactions may be shown as follows:



Lime is generally considered to improve the structure of acid soils, especially in fine-textured soils. The fine particles are granulated, making a soil with a crumb structure, which enhances air and water movement. This effect is largely indirect for better plant growth results from the addition of

TABLE 2-9. RELATIVE NEUTRALIZING VALUES OF PURE LIMING MATERIALS⁵

Liming materials	Relative neutralizing values	Pounds of liming materials equivalent to 1 ton of:	
		Calcium carbonate	Calcium oxide
Calcium carbonate.....	100	2000	3570
Magnesium carbonate.....	119	1680	3000
Calcium oxide.....	178	1120	2000
Magnesium oxide.....	250	800	1430
Calcium hydrate.....	135	1480	2640
Magnesium hydrate.....	172	1160	2070
Dolomite.....	108	1850	3330
Dolomitic hydrate.....	175	1145	2040

lime, which, in turn, means an increased organic matter supply for decomposition in the soil. The production of humus encourages granulation in soils.

Addition of lime encourages the action of beneficial soil organisms. This subject is discussed in Chapter 3.

At about a pH of 5.0 or less, complex phosphates of iron and aluminum may be formed. These complex phosphates have a very low solubility, therefore, are not readily available to plants. Lime applications raise the pH of acid soils, and at pH 5.0 or above the solubility of the soil phosphorus is increased, especially in the presence of CO₂. The optimum pH for making phosphates in a form available to plants is about 6.5 (Figure 2-5).

Soils may be overlimed. Too much lime reduces the availability of iron, phosphorus, manganese, boron, copper and zinc (Figure 2-5). The availability of potassium is also suppressed.

In alkaline soils low solubility of phosphorus results when the Ca₃(PO₄)₂ hydrolyzes in the presence of CaCO₃ as follows⁵⁸:



This reaction takes place at a pH of 8.0 to 8.5⁵³. In this pH range, the soil phosphorus may be highly insoluble and unavailable. Additional information on various aspects of soil reactions with lime are available elsewhere^{10, 99}.

Utilization of Calcium by Plants

Calcium is an indispensable element for the growth of all crops. Under natural conditions, plants with high calcium requirements are indigenous to the soils high in lime occurring in arid regions (Figure 2-10); in the East and South, plants with low lime requirement grow best on acid soils. When lime-loving crops, like sweet clover and cabbage are grown on acid soils,

lime has to be supplied by some liming material. Other plant growth factors must be considered for calcium is not the only determining factor.

All the functions of calcium in a plant are not definitely known but some^{59, 86, 102} are as follows:

- (1) Promotes early growth.
- (2) Increases plant vigor and stiffness of straw.
- (3) Encourages seed production.
- (4) Influences translocation of carbohydrates and certain mineral elements in the plant.
- (5) Influences root development.
- (6) Aids in neutralizing organic acids in the plant and in regulating the acid-base balance in plants.
- (7) It is essential for cell wall construction.
- (8) Influences, favorably or unfavorably, absorption of other elements by plants. For example, an inverse relationship has been found between the absorption of calcium and potassium by plants.

In animals, calcium is important in the development of bones and in the shell of eggs. If calcium is deficient in plants, and these plants are fed to livestock, the livestock may suffer from a deficiency of calcium. Plants deficient in calcium show characteristic symptoms of this deficiency, many of which have been published in color^{9, 22, 103}. Some calcium deficiency symptoms in plants are as follows:

- (1) The leaves have a wrinkled appearance.
- (2) Plants are stunted, becoming evident first in the new roots and leaves. The roots tend to be short and stubby because of their dying at the tips. There are few lateral branches of the roots.
- (3) In extreme cases, the leaves of the terminal bud curl, turn light green, and eventually die. The tips and margins are affected first.
- (4) As growth in deficient plants is retarded, the stems and often the lower leaves thicken and tend to become dark green.

Liming the Soil

Ground limestone, which is principally calcium carbonate, is usually applied as a source of calcium for soils, mainly because it is cheapest and most abundant in this country. Other liming materials and their relative neutralizing value compared with calcium carbonate are given in Table 2-9. Generally, the finer the limestone, the more quickly it reacts with the soil, neutralizing the soil acidity. The finer the material the greater the amount of surface exposed to the solvent action of the soil water. The coarser products are slower in action but have longer lasting qualities in the soil for it takes longer for the coarse particles to dissolve completely. The relationship of fineness of lime to time required for the lime to dissolve is given in Table 2-10⁷⁰.

TABLE 2-10. RELATIVE AVAILABILITY IN THE SOIL OF LIMESTONE PARTICLES OF DIFFERENT DEGREES OF FINENESS⁷⁰

Fineness of particles	Percentage available within 1 to 3 years	Percentage available within 8 to 12 years
Held on 20-mesh screen.....	20	50
Through 20-mesh screen but held on 60-mesh screen.....	60	100
Through 60-mesh screen.....	100	100

MAGNESIUM

The magnesium content of the lithosphere is estimated at 2.10 per cent⁶. Limestones are the most common source of this element for they always contain some magnesium, averaging about 5 per cent. Dolomitic limestones, which are high (to 21 per cent) in magnesium and the mineral magnesite are used as a source of supply. Magnesium is also found as an impurity in the potash minerals carnallite and kieserite²⁴.

Soil Magnesium Supplies

Surface soils generally contain less than 1 per cent of magnesia, though soils derived from serpentine have been found to contain more than 30 per cent⁵⁵. Sandy soils usually contain only traces of magnesium while soils high in clay contain higher amounts. A large part of the magnesia in soils is found in the colloidal fraction, and only about one-fourth or one-fifth of this is in the exchangeable or soluble form.

Magnesium is a constituent of many of the common soil-forming minerals such as biotite, augite, olivine, serpentine, talc, hornblende, and chlorite²⁴.

Losses of Magnesium

Magnesium deficiency often occurs on acid sandy soils, especially in seasons of heavy rainfall. Sandy soils on the Coastal Plains, Piedmont Plateau, in New England and also to some extent in other parts of the country are magnesium deficient.

Average losses from the soil by leaching, cropping and erosion are given in Tables 2-3 and 2-4.

Additions of Magnesium

Considerable amounts of magnesium are added to soils in fertilizers, liming materials, and barnyard manures (see Chapter 4 for amounts contained in these materials). Magnesium contained in liming materials and in fertilizers usually supply plant needs. Magnesium sometimes is applied in spray form either as high-magnesium lime in Bordeaux mixtures or as a 0.25 per cent solution of magnesium sulfate alone⁶. Other forms of magnesium used for correcting magnesium deficiency are calcined kieserite,

potassium-magnesium sulfate, magnesium-ammonium phosphate or magnesium carbonate²⁴.

Soil-Magnesium Relationships

Because magnesium compounds are very soluble and because magnesium is adsorbed by soil colloids, its deficiency in soils is probably greater than once thought²⁴. Magnesium is held in the soil in the silicate and carbonate form and as exchangeable ions on the soil colloids.

Magnesium undergoes chemical changes similar to calcium when added to the soil and the chemical reactions given above may also be considered representative for magnesium. In a representative humid-temperate region mineral soil, the amount of exchangeable calcium is approximately five times greater than exchangeable magnesium and ten times greater than potassium⁴⁹. About 25 per cent of the total calcium is exchangeable, and about 6.5 per cent of the total magnesium and 0.5 per cent of the total potassium.

Dolomitic limestones are only about two-thirds as soluble as calcitic limestones⁵⁰. Therefore, the particle size of dolomites must be reduced to very fine proportions before they are applied to soils. In areas intensively farmed, however, both calcitic and dolomitic limestones are ground to 100 mesh. The low-solubility disadvantage of dolomite may be compensated in part by its higher neutralizing value per unit of weight; 100 pounds of pure dolomite is equivalent to 108 pounds of pure calcite in correcting soil acidity (Table 2-9).

The availability of magnesium to plants in relation to the reaction of the soil is shown in Figure 2-5.

Utilization of Magnesium by Plants

Magnesium is an essential element for plant growth. It is a constituent of the chlorophyll molecule which contains 2.7 per cent magnesium¹⁰⁷. As a rule healthy plant leaves contain about 0.5 per cent of magnesia⁵⁵. Plants develop a characteristic chlorosis when the magnesium supply is insufficient.

Magnesium seems to play an important role in the transport of phosphate in the plant, and perhaps because of this, phosphorus accumulates in the seeds of plants rich in oil, for the oil is also accompanied by an accumulation of lecithin, a phosphate-containing fat⁷⁹.

The magnesium uptake of a plant apparently is affected by the amount of available potassium in the soil. If potassium is abundantly available to the plant, the magnesium content will be relatively low. It has been shown¹⁸ that an increased uptake of calcium and magnesium is accompanied by a corresponding decrease in uptake of potassium. Most crops contain more calcium than magnesium.

Magnesium compounds accumulate in seeds, fruits, flowers, roots and tubers to a larger extent than does calcium, but less in stems, leaves and wood¹⁰².

Magnesium appears to be especially important in the formation of seeds and in the formation of fat or oil in plants. Seeds rich in oil contain a larger proportion of magnesium than those rich in starch.

Plants develop a characteristic chlorosis when the magnesium supply is insufficient. This can be expected since magnesium is an essential component of chlorophyll. The degree of yellowing of the leaves takes various forms, depending on the plant. The lower leaves are affected first. In serious cases in some crops the plants are prematurely defoliated. Magnesium-deficient corn plant leaves show the deficiency by becoming striped, the veins remain green and the tissues in between white. In cotton and blueberries the leaves change to a purplish-red color, except for the stems and veins which remain green. Tobacco manifests a loss of green color between the veins beginning at the leaf tip and margins. In legumes, the deficiency is shown by chlorotic leaves. Symptoms of magnesium deficiency in various crops have been published in color^{9, 22, 103}. A symposium on magnesium fertilization and plant growth has been published in *Soil Science*⁸.

Magnesium deficiency often occurs on acid sandy soils that are also deficient in calcium, and a dolomitic limestone is used to correct both the calcium and magnesium deficiencies.

SULFUR

The lithosphere contains 0.06 per cent sulfur⁶, and the ocean 0.088 per cent³³. The most common sulfur-containing minerals in soils and rocks are pyrite, gypsum, and anhydrite. Soils of humid regions average about 0.05 per cent sulfur, or 1,000 pounds of sulfur to plow depth. Soils in parts of the United States, especially Oregon, Washington, Minnesota, and Florida, are deficient in sulfur. Since sulfur is an important constituent of organic compounds, the sulfur content of soils in humid regions is related to the amount of organic matter in soils. Sulfates sometimes are constituents of alkali salts in irrigated soils of dry climates (see Chapter 1 on Soils).

Losses and Additions of Sulfur

Leaching of sulfur from soils varies with precipitation from about 20 to 50 pounds per acre annually²⁴. In most areas, sulfur losses are replenished by that brought down by rain and snow. The amount depends on location, ranging from 2 or 3 pounds an acre annually to over 100 pounds near industrial centers⁴⁹. Average losses from leaching, erosion and crop removal are given in Tables 2-3 and 2-4. Sulfur is added by applications of manures and commercial fertilizers; for example, ammonium sulfate contains 59

per cent SO_3 and superphosphate 30 per cent SO_3 (see Table 4-14, p. 114). The more modern fertilizers carry little or no sulfur. Elemental sulfur is applied to alkaline soils in the far west to reduce the alkalinity of the soils.

Soil-Sulfur Relationships

Weathering of sulfur-containing minerals probably is the chief source of sulfur in soils. In humid regions, most of the sulfur is present in soils in the form of organic sulfur compounds in the soil organic matter. The sulfur is gradually oxidized to sulfates by microorganisms (see Chapter 3). They are largely soluble in this form and are readily leached from the soil. In contrast to soluble phosphates, the phosphates are quickly fixed on contact with the soil and little, if any, is leached out of the soil (see Phosphorus above).

In semiarid and arid regions, calcium sulfate (gypsum) and even the more soluble sodium sulfate frequently occur as soil components. When soils are submerged under water for a period of time, sulfates are reduced to sulfides, hydrogen sulfide is given off, imparting the characteristic odor. The soil becomes very toxic.

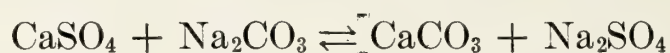
Elemental sulfur is applied to soils to increase their acidity so that certain acid-loving crops such as rhododendrons and azaleas may be grown. Sulfur is used on potato soils to lower the pH values to about 5.2 in an attempt to control potato scab (*Actinomyces scabies*). Sulfur is often used by market gardeners to acidify soils which may have been overlimed. The increased acidity increases the availability of some of the minor elements. Sulfur has been used on the burnt-over peat and muck soils of Florida to increase the acidity of the soil so that more manganese is available for succeeding crops²⁴. Aluminum sulfate or ferrous sulfate is often used instead of elemental sulfur. Ammonium sulfate is also used for acidifying soils, especially where nitrogen is also needed for fertilizing purposes (see Table 2-7).

Elemental sulfur and gypsum are used for correcting the unfavorable high alkalinity and dispersed structure of alkali soils. These soils are high in sodium and potassium carbonates. Adding sulfur as elemental sulfur converts the carbonates to sulfates, which also decreases the pH. Sodium sulfate is about neutral in pH and can be leached out of the soil by repeated irrigations. Plants can stand from two to three times more sodium sulfate than sodium carbonate. Gypsum has an advantage in supplying calcium to displace sodium, and also sulfur to react with the sodium carbonate to form sodium sulfate. Insoluble calcium carbonate is also formed which is lower in pH than the soluble sodium carbonate, a combination which lowers the pH in the soil. Removal of the sodium carbonate improves the structure of the soil, removing the dispersive action on clay, and promoting an aggregated instead of a puddled soil.

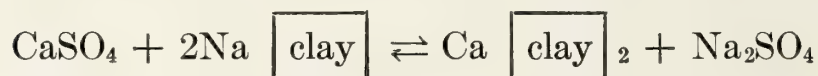
Soils high in sodium require high applications of gypsum for corrective action. More than 20,000 pounds per acre has been used. Generally, gypsum has given best results on soils high in sodium, and sulfur on soils containing some calcium carbonate and smaller amounts of sodium. Adding organic matter to the soil stimulates the oxidation of the sulfur to the sulfate form. A combination of sulfur, manure, and gypsum has been found to give maximum benefits in correcting alkali soils⁵². The use of alkaline soils for crop production is discussed by Hayward and Wadleigh³⁷ and Thorne and Peterson⁹⁷.

The following chemical equations illustrate the manner in which the various amendments react⁷⁴.

Gypsum



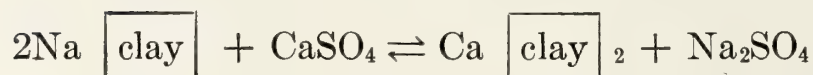
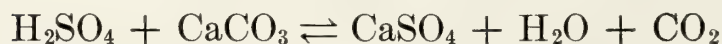
(Na_2SO_4 can be readily leached)



Sulfur



(microbiological oxidation by sulfur bacteria in the soil)



Utilization of Sulfur by Plants

Sulfur is one of the important elements which enters into the synthesis of organic compounds. It occurs in plant tissues chiefly in the form of proteins, volatile compounds, and sulfates. It occurs in the so-called oils such as mustard oil, which are characteristic of the cruciferae, i.e., mustard, turnips, cabbage, radishes, etc. The proteins of plants contain from 0.033 to 7.2 per cent sulfur⁵⁹. It appears to be essential for protein production for alfalfa grown in Washington to which sulfur was added was higher in protein than the check. Sulfur apparently is related to nitrate reduction for plants deficient in sulfur tend to accumulate nitrate nitrogen.

Sulfur has been found to increase the root system of plants like alfalfa, clover, and rape. Plants in soils deficient in sulfur have a pale-green color. Apparently, sulfur increases the chlorophyll content of plants⁵⁹. Nodulation is improved in legumes by adding sulfur to sulfur-deficient soils. Plants

may take up sulfur, chiefly as sulfate, directly from the soil, or SO_2 may be absorbed by the leaves from the atmosphere.

Sulfur-deficiency symptoms in plants are similar to nitrogen deficiencies^{9, 22, 103}. On affected plants, the leaves are pale and tend to become yellow, shoot growth is retarded and erect, the stems develop woodiness and the roots become abnormally long. Sulfur-deficient plants, unlike those nitrogen deficient, do not lose their leaves by firing and the new growth rather than the whole plant turns yellow.

Sulfur deficiencies, like those for potassium, tend to develop in dry seasons. Rain may alleviate moderate sulfur deficiencies in areas of heavy industrial development. Wheat, corn, oats, timothy, alfalfa, rape, beets, potatoes, turnips, radishes, beans, tobacco and grapes grown in sulfur-deficient soils have benefited by sulfur applications. Generally sufficient sulfur is added to soils in fertilizers or barnyard manure (see Table 4-14, p. 115) to maintain the sulfur supply in the soil. Elemental sulfur or gypsum can be added to soil if they are sulfur deficient.

SODIUM

The average sodium content of the lithosphere is 2.83 per cent³³, a somewhat higher percentage than for potassium. About 30 per cent of the salts in the ocean is made up of sodium²³ compared with about 3.8 per cent for magnesium, 1.2 for calcium, and 1.1 for potassium. The common soil-forming minerals, orthoclase, plagioclase, diorite, and the plagioclase feldspars contain 1.5 to 6.0 per cent sodium²⁴.

Most minerals that contain sodium are susceptible to rapid weathering. In humid climates most of the sodium converted into soluble compounds is leached from the soil and carried to the sea in drainage waters. These soils, therefore, contain only a small percentage of sodium, ranging from 0.05 to 3.0 per cent to plow depth, depending upon the rainfall they have been subjected to. Since sodium constitutes such a small part of the exchange complex of these soils, they are usually ignored.

In arid regions, large amounts of sodium salts often accumulate as surface incrustations. Sodium salts make up as much as 90 per cent of the alkali in some of the soils in the western states³⁵. In "black alkali" soils sodium carbonate is prevalent. The pH readings usually range between 8.5 and 10. Sodium in the carbonate form dissolves and disperses the humus in the soil and deflocculates the soil, making it many times nearly impervious to air and water. The dark color is due to the dispersed humus, hence the name "black alkali." When attempts are made to grow crops by irrigation methods on these soils, the high amounts of sodium salts cause injury to the plants. The tolerance of plants for salinity conditions is given in Table 2-2.

The so-called "white alkali" soils are high in soluble sodium salts exist-

ing mostly in the chloride and sulfate forms. When adequate drainage is established, the excessive soluble salts may be removed by leaching and by crops grown on the soils⁷⁴. Ordinarily, the pH of these soils is less than 8.5.

Corrective measures used to improve the productivity of alkaline soils are discussed under Sulfur above.

Utilization of Sodium by Plants

Most plants contain sodium and the amount of sodium in plants varies, not only with the kind of plant, but also with the amount of sodium in the soil in which the plant is grown. Sodium is generally not considered essential to the growth and development of the plant but its presence apparently exerts a marked effect on the growth of some plants, especially if the soil is not well supplied with potassium⁵⁹.

Benefits observed from the use of sodium salts have been ascribed to four possible roles⁶ that sodium can perform in the plant as follows: (a) Sodium can apparently perform certain functions of potassium. Potassium has several functions in the plant, one of which is specific to potassium whereas the others are more or less general and may be performed by sodium, calcium, and magnesium. It may delay potassium starvation for the plant but cannot keep it off entirely. (b) On application of sodium salts to the soil more of the soil potassium is released from the exchange complex, thereby benefiting the crop. (c) Sodium tends to aid in maintaining soil phosphorus in a more available form than would otherwise occur. (d) Sodium has value as such for certain species of plants, especially those that tend to be high in their content of sodium such as plants native to arid areas or along the seashore.

Sodium is now known to have a direct value to certain plants especially beets, mangels, Swiss chard, celery, cotton, celeriac, cabbage, kale, kohlrabi, radishes, rape and turnips. Marked increases in yields from Swiss chard, table beets, sugar beets, cabbage, parsnips, carrots, cotton, turnips and potatoes have been obtained from the use of common salt^{2, 6}. Studies of sodium as a fertilizer³⁴ brought out that crops can be divided into four groups depending on whether potash was deficient or adequate. These four groups are shown in Table 2-11. Perhaps one reason why sodium has been neglected in plant nutrition studies is that large amounts have been added to the soil in sodium nitrate, a widely used fertilizer. Additional information on the relationship of sodium to fertilizer practice and crop production in humid regions is given in a symposium¹¹.

TRACE ELEMENTS

Plants need very small amounts of certain elements—now commonly called trace or minor elements—for their nutrition^{20, 31, 90}. These elements

TABLE 2-11. EFFECT OF SODIUM APPLIED AS A NUTRIENT ON SEVERAL CROPS³⁴

Degree of benefit in deficiency of potassium		Degree of benefit in sufficiency of potassium	
None to slight	Slight to medium	Slight to medium	Large
Buckwheat	Asparagus	Cabbage	Celery
Corn	Barley	Celeriac	Mangel
Lettuce	Broccoli	Horse-radish	Sugar beet
Onion	Carrot	Kale	Swiss chard
Potato	Cotton	Kohlrabi	Table beet
Rye	Flax	Mustard	Turnip
Soybean	Millet	Radish	
Spinach	Oat	Rape	
Strawberry	Pea		
Sunflowers	Tomato		
White bean	Wheat		

are iron, manganese, boron, copper, zinc and molybdenum. They are called trace elements because only very small quantities, ranging from a few ounces to a few pounds per acre, are needed for most crops. Some soils are naturally deficient in one or more of these elements or they occur in exceedingly small amounts^{12, 55}. Figures 2-11 and 2-12 show areas in the United States where trace element deficiencies in plants have been found¹³. A symposium on minor elements has been published in *Soil Science*⁷.

The function of all these minor elements is not well understood. Their effect on plants may be curative rather than nutritive. They may affect plant growth⁵⁸ in one or more of the following ways: (a) act as catalysts or stimulants; (b) are constituents of plant tissue; (c) effect oxidation-reduction processes in the plant; (d) may aid in regulating the acid content of the plant; (e) may affect the plant osmotically; (f) may affect the entrance into the plant of other elements; or (g) may aid plant growth by providing a more favorable environment for the plant roots.

The addition of all of these trace elements to fertilizers without regard to the soil or crop is unwarranted and generally would prove injurious to the crops. In some areas, certain of the minor elements, such as boron, are added to the fertilizer when the soil is known to be deficient. Some fertilizers naturally contain one or more of the minor elements. The amount of trace elements found in some commercial fertilizers is given in Table 4-14, p. 114). Barnyard manures contain small amounts of minor elements (Table 4-2, p. 91), but generally they do not contain sufficient amounts to correct soils deficient in given deficiencies⁴. Sometimes instead of applying minor elements to the soil it is easier, cheaper, and more effective to spray the minor element on the leaves of the plant, or, in the case of trees, to insert the minor element under the bark.

organic nitrogen fertilizers and barnyard manure has diminished; some soils are lower in organic matter than formerly; and some deficiencies are related to loss by erosion of the soil.

Recently, interest has developed in adding trace elements to the soil in a form known as "fritted trace elements"^{43, 105, 106}. When trace elements are applied to the soil in a highly soluble form, they are very susceptible to loss by leaching and fixation. A method has been developed whereby trace elements are embodied in a matrix of glass and applied to the soil as a finely ground powder. The trace elements become slowly available to plants, supplying sufficient quantities during the growing season for healthy plant development. Iron, manganese, copper, zinc, boron and molybdenum have been incorporated in one product at percentages of about 5 per cent or less for each metal. They may be applied directly to the soil or as an additive in commercial fertilizers. About 100 pounds per acre is the suggested application rate.

Boron

Although boron availability is decreased in many cases by an excess of lime, the greatest areas of boron deficiency (Figure 2-11) are found in the humid regions where the soils are generally acid¹⁴. In regions of low rainfall the boron content of soils is high. Boron in soils generally is in the form of the highly insoluble mineral tourmaline. The total boron content of soils ranges from 2 to more than 100 ppm with 30 to 40 ppm as an average⁷¹.

Boron appears to be concerned with the uptake of calcium by the roots and with its efficient use in the plant⁷⁹. Plants grown on soils high in lime have a higher boron requirement because of increased calcium uptake. Overliming a soil reduces the uptake of boron by plants for boron availability decreases as pH rises (Figure 2-5). The principal nutrient deficiency symptoms^{9, 14, 22, 86, 103} are: (a) black or brown spots in root crops, cabbage, kohlrabi, cauliflower, and similar crops; (b) black spots, cankers, or lesions on the outside of root crops and tree fruits; and (c) chlorosis on legume crops, cracked stems of celery, cracking in root crops and fruits, and terminal bud injury (rosette) in trees, shrubs and flowers. In areas where alfalfa is grown, this crop is a good indicator.

Substantial increases in yield have been obtained from various crops from applications of from 10 to 40 pounds of borax per acre. The trend is for many companies to add borax to their fertilizers in areas of boron deficiency. The fertilization of soils with boron should be done with caution. No other plant nutrient has such a narrow range between the amount required for optimum growth and the amount necessary for toxicity. The boron requirement of several crops is given in Table 2-12. Page and Paden⁶² believe that with more intensive farming in conjunction with more liming and use

TABLE 2-12. BORON REQUIREMENT OF SOME COMMON FIELD AND VEGETABLE CROP PLANTS¹⁴

Probable available boron content of soils (ppm) required for optimum growth

Plants with high requirements > 0.5 ppm	Plants with medium requirements 0.1 to 0.5 ppm	Plants with low requirements < 0.1 ppm
Apple	Tobacco	Wheat
Alfalfa	Tomato	Oats
Red clover	Lettuce	Rye
Crimson clover	Peach	Barley
White clover	Cherry	Buckwheat
Sweet clover	Olive	Corn
Red beets	Pecan	Soybeans
Sugar beets	Cotton	Peas
Mangels	Sweet potato	Green beans
Turnips	Peanut	Lima beans
Cabbage	Carrot	Navy beans
Broccoli	Walnut	Strawberry
Cauliflower	Filbert	Citrus
Asparagus	Onion	Raspberry
Sunflower	Pear	White potato
Radish		Blue grass
Brussels sprouts		Brome grass
Celery		Other grasses
Rutabaga		Flax
Burr clover		

of higher analysis fertilizers, boron deficiency will increase in the southeastern United States.

Manganese

Manganese occurs in the soil in different forms with widely divergent solubilities. Therefore, a distinction must be made between total and available manganese. The amount of available manganese ranges from 20 to 200 pounds per acre⁹⁶. This element exists in most soils as the dioxide or the hydrated oxide in the minerals pyrolusite, manganite, and psilomelane²⁴. In some soils, the manganese content is related to the soil parent material^{17, 24} and in others, removal of the plow layer by erosion exposes subsoils deficient in manganese.

Manganese is most likely to be deficient in overlimed or calcareous soils or in strongly leached sandy soils. Toxicities may occur in acid soils naturally high in manganese in the mineral form¹⁷. The occurrence of manganese deficiencies in plants in the United States is shown in Figure 2-11.

Manganese appears to play the role of an activator in many enzymatic reactions in plants. There is evidence that this element plays an important role in the photosynthetic apparatus of green plants and together with iron controls the oxidation-reduction potentials in the cells during illumination

and in the dark⁶¹. The manganese content of plants is always low¹², seldom exceeding a few hundredths of a per cent on a dry weight basis.

The manganese content of a variety of plants grown under identical soil conditions show that inherent differences do exist among plants in their uptake of this element^{98a}. The highest manganese content for legumes, 75 ppm, was obtained in the second cutting of alsike clover. Sudan grass was lowest, 22 ppm, and orchard grass, 77 ppm, highest of the grasses examined. Rye forage with 110 ppm was highest for the cereals and corn grain lowest with 4 ppm. The manganese content of the vegetables ranged from 9 to 73 ppm. The bulbs, tubers, or roots contained less manganese than did leafy vegetables. Of the nine weed plants examined pigweed (*Amaranthus retroflexus*) contained the most manganese (65 ppm).

Deficiency of manganese in plants shows up first in a chlorotic condition in the leaf area between the veins while the veins themselves remain green. The detailed symptoms among plants are varied^{9, 22, 103}.

Manganese deficiency in field crops can be corrected by applying from 50 to 100 pounds per acre of manganese sulfate to mineral soils; up to 400 pounds per acre are applied to alkaline peat soils⁷¹. A weak solution of manganese sulfate is also sprayed directly on the leaves to correct deficiencies of this element. Soils fertilized with manure are not likely to develop manganese deficiency. Manganese toxicity in a soil may be corrected by applying lime or phosphates.

Iron

This element appears to catalyze the production of chlorophyll. Iron deficiency typically shows up as a chlorosis; the leaves turn bright yellow in color^{9, 22, 103}. The lack of iron in plants usually results from its unavailability under certain soil conditions rather than from a lack of supply in the soil. Iron is usually unavailable in soils high in calcium carbonate at a high pH (Figure 2-5), and in soils high in manganese. Iron is more available to plants in the reduced than in the oxidized state. Ferrous oxides are toxic to many plants. Drainage and use of soil management practices which aerate the soil generally will alleviate iron toxicity. The occurrence of iron deficiencies in plants in the United States is shown in Figure 2-12.

The newest and most effective method for correcting iron deficiency is to apply the chelated forms of iron to the soil^{22, 89}. An example of these chelating chemicals is ethylenediamine tetraacetic acid, known as EDTA. These chemicals have the ability to combine with metals and hold them in a nonionized form from which they cannot be precipitated from solution under most conditions. The use of chelated metals for growing plants is given elsewhere^{22, pp. 775-809} by Stewart and Leonard. Iron deficiency is also controlled by spraying the leaves with a 1 or 2 per cent solution of ferrous

sulfate or by placing ferrous sulfate in the soil under trees, by injecting iron phosphate into holes bored into the trunks of trees, or by driving iron nails into the trunks, or by acidifying the soil.

Copper

Soils vary in copper content from one to about 50 ppm⁵⁵, yet plants are able to obtain the amounts required for normal growth from most soils. Copper deficiency is most frequent on very sandy or gravelly soils and on peat and muck. In Australia the deficiency is acute on some highly calcareous sands¹⁰³. Liming reduces the availability of copper in deficient soils. Areas deficient in copper in the United States are shown in Figure 2-12. Little is known of the factors affecting the availability of copper to plants, but organic matter, soil organisms and pH are all important.

All plants contain some copper, and most plants contain less than 10 ppm. They normally show toxicity at 30 ppm³¹. The amounts in plants vary, depending on species, soil, the amount of fertilizer used, and other factors³². Copper deficiency has been reported for citrus, olive, pear, tung, plum, oats, flax, wheat, lettuce, peas, tomatoes, tobacco, sweet corn, potatoes and onions.

Apparently copper has an indirect function in chlorophyll formation, although the chlorophyll molecule contains no copper³². Copper not only increases the chlorophyll content of some plants but it also has a protective effect against chlorophyll destruction, resulting in longer plant life. Copper is important as a constituent of at least three enzymes—ascorbic acid oxidase, lactase, and tyrosinase.

An early symptom of copper deficiency is an unusually dark green color of the leaves. Later, the leaves become chlorotic, turning a yellow-green color, and the plant suffers a general collapse of growth. Deficiency symptoms for several plants are shown in color elsewhere^{9, 22, 103}.

Copper sulfate applications to the soil or through the use of a spray (Bordeaux mixture, etc.) on the foliage, especially on trees, have been used successfully to correct copper deficiency. Application of from 10 to 30 pounds of copper sulfate per acre is sufficient for most soils. Some soils require 50 to 200 pounds per acre²⁴. Too large amounts applied to sandy or gravelly soils may be toxic to plants because of the low buffer capacity of these soils.

Zinc

Various analyses show this metal to range in soils from 2 to 50 ppm. The smallest quantities are found in sandy soils low in organic matter⁵⁵. The availability of zinc declines as the soil pH rises, the critical point being between pH 5.5 and 6.5²¹. Zinc is believed to exist in soils in water-soluble,

exchangeable, and a relatively insoluble fraction composed of phosphates, carbonates and silicates, or other stable compounds³⁹.

Zinc deficiency has been reported from all the citrus growing areas in the world. Zinc deficient areas and the kinds of plants showing deficiencies in the United States are shown in Figure 2-12. Beneficial results have been obtained from application of barnyard manure to some crops due primarily to the zinc contained in the manure. Natural organic materials in fertilizers may also be a source of zinc²¹. To overcome deficiencies, zinc sulfate applications of 10 to 50 pounds per acre are made. Better results on soils with a pH above 6.5 has been obtained by spraying the foliage with zinc sulfate at a rate of about 2 pounds of the chemical in 50 gallons of water⁷¹. Weeds and grasses, notably ragweed and lamb's quarter, are able to obtain more zinc from soils that are low in zinc than most cultivated crops⁷⁹. Such weeds may have value as cover crops for plowing under as sources of zinc in zinc deficient soils.

Viets *et al.*^{102a} have tentatively classified field and vegetable crops on their sensitivity to zinc deficiency in soils as follows:

Very sensitive

Beans
Soybeans
Corn
Hops

Grapes
Lima beans
Flax
Castorbeans

Mildly sensitive

Potatoes
Tomatoes
Onions
Alfalfa

Grain sorghum
Sudan grass
Sugar beets
Red clover

Insensitive

Peppermint
Oats
Wheat
Barley

Rye
Peas
Asparagus
Mustard

Carrots
Safflower
Grasses

The role of zinc within the plant is not yet understood but it is believed to be necessary for chlorophyll formation and growth. The average content of zinc in plants is probably less than 50 ppm on a dry-weight basis. Zinc deficiency usually produces some form of leaf chlorosis⁵⁵. Bronzing of tung leaves, spotting of the lower leaves in tobacco, "little leaf" or "mottle leaf" of citrus, "rosette" of peaches and pecans, and "white bud" of corn are typical plant disorders corrected by zinc salt applications. Zinc deficiency symptoms in color have been published for several plants^{9, 22, 103}. In any considerable amount zinc is poisonous to most plants.

Molybdenum

Of the trace elements, molybdenum apparently is taken up in the smallest quantities by plants. The distribution of molybdenum in soils and plant tissues is extremely wide⁹⁵. From 0.01 to 9.0 ppm has been found in plants, and 0.1 to 0.3 ppm total in fertile soils. Peat soils contained only one tenth this amount and barren sands 0.005 ppm. Most soils contain enough available molybdenum for crops to grow satisfactorily.

Deficiencies have been observed in Australia, New Zealand, Tasmania⁷⁹, and in the United States⁴⁴, especially in the highly leached sandy soils of the Atlantic and Gulf coastal plains, and the Pacific Northwest. Plants affected by this deficiency include high-lime requirement crops such as cauliflower, clovers, and alfalfa. In acid-soils, the solubility of most of the trace elements is reduced by liming. Molybdenum differs from the other trace elements in that liming increases its solubility. One of the most important effects of liming, according to Bear⁶, may be that of making soil molybdenum available. Under alkaline conditions, little rainfall is necessary to remove molybdenum by leaching.

About one ounce of molybdic oxide per acre is applied to the seed or to the soil in deficient soils. One pound of sodium molybdate per acre applied to alfalfa in New Jersey⁶ gave a yield increase of 13 per cent. Foliar spray applications have been widely used in Australia and New Zealand⁴⁴ on vegetable crops, pastures, clovers, alfalfa, rutabagas, and wheat. In a few areas, sodium molybdate is dusted on by air. The salt is generally mixed with some ground limestone or other inert material to give greater bulk. Treatment of the seed by dusting or soaking has also been employed successfully. Sodium molybdate and ammonium molybdate are water-soluble and easy to apply in solution form. Molybdic oxide is not soluble in water and must be applied in mixed fertilizers.

Molybdenum is absorbed as the molybdate ion. The solubility of molybdenum is low at low pH values because molybdenum is precipitated by iron. Rock phosphate and superphosphate often contain small quantities of molybdenum so where these fertilizers are used one would not expect plants to show molybdenum deficiency.

Legumes are unable to fix nitrogen in the absence of an adequate molybdenum supply. Every nitrogen-fixing organism requires molybdenum for this purpose. Apparently, this element operates as a catalyst in the reduction of atmospheric nitrogen to ammonia by the bacteria in the nodules on the roots of legumes. Without molybdenum, nodules form, but the bacteria do not function⁴⁴. It is also essential in the reduction of nitrates to ammonia in nonlegume plants. Molybdenum may also be essential to the formation of chlorophyll and to several plant enzymes. In large amounts, molybdenum is toxic to plants.

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3. SOIL MICROBIOLOGY

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Soil Microorganisms

Soil has already been described as any portion of the earth's surface upon which crops grow. Its chemical components have been discussed and means have been indicated by which the necessary level of plant food for named crops can be maintained. Microorganisms have been noted as present in all soils but their character and significances will be discussed in this chapter.

Crop growing is a biological process. Its success is measured by the completeness of the growth conditions for the particular crop. The kind of micropopulation encountered is a major factor in successful farming even though it is often unrecognized.

The term microorganisms strictly interpreted would apply to such living things as can be seen only with the microscope. In practical application the term "soil microbiology" is commonly used to include all processes in the soil which are known to be or inferred as due to the activity of bacteria, actinomycetes, molds, algae, protozoa, or such other complex organisms as are indistinguishable by the naked eye. One may safely say that wherever a green plant grows, the microbiologist can demonstrate the presence of many groups of such living organisms in or on its leaves, stems and roots and in the soil about it, wherever the remains of previous growth of plant or animal tissue are found. The soil is a great leveler. Every plant or animal that ever lived eventually returns to the soil in some form. That statement necessarily includes the observation that every species of the microorganism ever described or not yet described has been carried into the soil somewhere if it was not indigenous there. Hence the possibility stands that exhaustive search over a wide enough range of soils might find any such organism whether useful, useless, harmless or dangerous to man.

For our purposes here the microorganisms of the soil may be roughly grouped under three headings.

(1) The cosmopolitan organisms of decomposition reduce waste products to soil organic matter which is agriculturally important. These constitute probably 80 to 90 per cent of the total population.

(2) Organisms related to specific soil activities, such as nitrogen fixers, nitrate formers, sulfur bacteria, etc.

(3) Organisms present but inactive in the soil such as the organisms of tetanus, of botulism, or various plant diseases.

Studies upon soil population were begun by bacteriologists and have been continued by bacteriological plating methods, hence bacteriological findings form the basis of most of the generalizations in the literature. The data presented here will be based primarily upon the calculations as to soil bacteria. Consideration of other groups will follow.

The limitation of the routine bacteriological plating method must be recognized. The organisms obtained in culture are primarily aerobic and in each case only those capable of growth in the particular culture substratum are found. Naturally the results vary because the procedures of different groups of workers present quite striking contrasts. Soils differ sharply in reaction (pH). Acidic soils present selective floras of acid tolerant species; definitely alkaline soils show a different selectivity. Strictly anaerobic forms do not appear in petri dish culture. Incubation temperatures are also significant.

Certain series of species can be isolated only upon selective or enriched substrata based upon particular factors in their metabolism. Whole groups of nitrifiers, sulfur bacteria, iron bacteria, anaerobic Clostridia, whole series of molds, etc., fail to appear in the ordinary petri dish culture but can be demonstrated by special methods. The ordinary population count has however served well as a comparative indicator of general biological activity of series of soils.

Enumeration of microorganisms presents many problems. The mineral particles of the soil constitute much of its mass so packed as to leave larger or smaller free space throughout. These mineral particles are not penetrable by organisms, which must find their habitat in other components usually distributed unevenly among or upon the mineral particles. Bacteria are essentially aquatic, or like molds, semiaquatic; hence both must live in or in contact with the water solution of such elements as may be in the soil, mixed with whatever colloidal material is present, the solution forming a film which envelops the soil particles and lines the pores. The percentage of the mass of a soil occupied by the pores is said to vary with the type of soil. Such a watery film in moist soil is assumed to be continuous, whereas under very dry conditions it may be reduced to thin films about individual par-

ties and groups of particles. In such films these microorganisms may move freely as individuals or as groups of cells, when water is abundant, or become essentially encased in mud under conditions of drought. Obviously then, bacteria dependent upon nutrients distributed unevenly will develop actively if food is plentiful and remain as scattered individuals or clumps if food is scanty. Uniform distribution is not to be expected. Such factors complicate the determination of numbers in the microbial population. For a broad study of microbial population samples of soil must be so spaced and sufficiently comprehensive as to offset a condition such as will cause marked differences in numbers in samples even taken 6 feet apart, as reported by the Rothamsted group. Totals when found have no exact significance but can be used in comparison with studies of other soil as, in general, indicative of comparable biological conditions.

Total Populations

Something of the size of such micropopulations is therefore important. Here we may quote Sir John Russell,¹² "About 20,000,000 bacteria per gram of soil is now considered a fair average number." But this figure, taken from his book, must be qualified by adding that it represents Rothamsted neutral cropping soil in fallow condition, such as a field that has stood over winter without cultivation and samples that are free from obvious decaying organic matter. His figure further applies to bacteria, omitting actinomycetes, molds, protozoa, etc., which would call for at least 5,000,000 added to his own total. There have been many attempts to establish exact numbers for particular soils or perhaps more accurately for particular samples. Many bacteriological culture procedures have been developed by various groups of workers. No two of them yield the same figures, probably because no two of them permit the development of the same fraction of the vast number of species found in any particular population. Their value lies rather in comparative studies of series of samples of the same soil under contrasting conditions of culture and fertilization, and of series of soils differing in character but studied under common conditions and unified procedure. In any case, for discussion of cropping soils it has been profitable to take the amended Russell figure of 25,000,000 per gram as a good base line for such soil in microbially static conditions.

Since the great majority of these studies has been bacteriological, the discussion of numbers of organisms here applies to bacteria unless molds are specified.

In contrast to this 25,000,000 base line for a good cropping soil in static condition, a comparison of figures from many sources justifies presenting contrasting figures for some extreme soil conditions. Again it must be noted that exact figures mean little.

TABLE 3-1. COMPARATIVE BACTERIAL POPULATION IN GREENHOUSE SOILS

Time following application of treatment (days)	3	8	14	24	43	60
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	Bacterial numbers*					
Chicken manure added	1,351	1,551	1,170	739	408	310
Chopped alfalfa added	618	275	160	93	122	165
Untreated	27	56	85	44	53	38

* Numbers for 1/1,000,000 dilution of 1 gram of air-dry soil.

Bacteria counts obtained by culture.

Sandy Soils—desert types—up to a few thousand to the gram
Acid clays—unproductive—perhaps about 1,000,000 to the gram
Poor grade loam, untilled—up to 10,000,000 to the gram
Untilled field soil—(cropping soil in inactive state) 20 to 50 million to the gram
Manured soil freshly tilled—any figure up to billions to the gram

As illustrating the range of figures possible when man's intervention is introduced, Table 3-1 presents Clark's experiment showing how the presence of decomposing manure affects the total count, compared to that induced by adding chopped alfalfa, compared to the count of the original soil and then how the high figures drop in a few weeks by the disappearance, apparently by death, of vast numbers of such bacteria so that the bacterial condition of the soil falls toward the static figure.

The continuity of the rotting process upon the surface of the soil with that just below the surface is suggested in Table 3-2 from work in the Soil Microbiology Laboratory at Washington.

The same idea is further exemplified by Table 3-3 which adds the effect of neutralization, thus showing how man's operations can affect the soil population to a startling degree.

The great numbers of microorganisms as shown by Table 3-3 are very crowded in the top 6 inches. Extensive studies by Hutchins⁸, Leather⁹, Lundegardh¹⁰, Smith and Humfeld¹⁶ have shown that such microorganic activity floods the pores in the top soil with carbon dioxide. Oxygen suffi-

TABLE 3-2. PLOT WITH GREEN VETCH ADDED UPON THE SURFACE AS DETERMINED ON THE 1ST DAY AND AFTER 11 DAYS OF DECOMPOSITION AT ABOUT 28°C*

	On 1st day	After 11 days	On 1st day	After 11 days
Green vetch	363,000	28,580,000	159,000,000	8,900,000,000
0-1/4 in.	834,000	1,410,000	142,000,000	65,200,000
1/4-1/2 in.	288,000	326,000	60,000,000	55,300,000
1/2-1 in.	297,000	298,000	37,800,000	36,500,000
1-2 in.	238,000	220,000	42,200,000	32,100,000

* Cultures and tabulation by Harry Humfeld.

TABLE 3-3. MILLIONS OF MICROORGANISMS IN SOIL AT VARIOUS DEPTHS WHEN UNLIMED AND LIMED AND IN FRESH AND DECOMPOSING GREEN MANURE (Calculated on the basis of dry weight)

Days after green manuring	Microorganisms in unlimed soil at indicated depth (in.)			Green-manure layer, millions	Days after green manuring	Microorganisms in limed soil at indicated depth (in.)			Green-manure layer millions
	0 to 2 millions	2 to 4 millions	4 to 6 millions			0 to 2 millions	2 to 4 millions	4 to 6 millions	
0	7.5	7.9	11.1	970	0	43.9	45.6	35.1	970
2	6.4	5.3	7.7	7,350	2	47.6	36.3	20.0	8,800
4	13.4	10.1	11.0	21,500	4	52.6	29.9	34.2	46,400
7	21.0	18.8	20.5	5,430	7	61.3	48.1	66.6	5,000
14	12.5	8.4	13.3	800	14	32.0	34.5	23.8	760
21	23.1	17.2	27.5	508	21	60.1	37.0	39.4	420
35	10.6	8.7	8.7	352	35	44.8	47.6	24.0	178
56	13.7	3.7	10.8	73.5	56	75.0	39.6	32.2	87.6

Decomposition of vetch green manure in relation to the surrounding soil, by N. R. Smith and H. Humfeld. *J. Agr. Res.*, 44 (2), 113-120 (1932).

cient to maintain such activity is limited to the top few inches, the exact depth depending upon the nature and porosity of the soil. Collectors of gases escaping at the surface have shown the escape of carbon dioxide at all times indicating that the fluid lining the pores tends toward saturation with carbon dioxide because the excess only tends to escape. Numerous studies while showing the survival of many organisms in the deeper layers have produced little evidence of great activity axcept where cracks, worm holes or rodent holes furnish ventilation. Although such accessories to population development are common, they rarely are uniformly present.

Fungi

Gilman⁶ collected the names of about 1,000 fungi (excluding the fleshy forms such as mushrooms and puffballs) which have been reported from the soil by various workers. Many of them were listed by collectors as being found vaguely in soil. Probably the list would be greatly lengthened by systematic field work. The great groups of fungi are all represented thus justifying the observation that all such organisms reach the soil in some manner and that many of them remain viable while some actually take part in soil processes.

Shantz and Piemeisel¹⁵, working in Colorado, demonstrated that mushrooms and puffballs produced fruit bodies in "fairy rings" hundreds of feet in diameter whose masses of mycelium were readily observable; the mycelia formed thick layers about 2 inches below the surface through large areas. Smaller fairy rings are well known features of grassy areas

everywhere and have been identified as representing many genera of fungi, mostly in Basidiomycete series. In one area in southern Virginia, Thom reported the mycelium of a *Clavaria* about 1½ inches below the surface and apparently spread over several acres on a mountainside. The whole area was dotted with clumps of *Clavaria* fruit bodies separated almost in checkerboard fashion.

Enough research work has been done with a few species to demonstrate their significance in the breakdown of plant remains, especially the cell wall materials, including cellulose and lignins.¹

Numbers as recorded in culture from soil usually represent colonies grown from fragments of hyphae developed in the pores of the soil and broken to bits by the dispersion procedure used by the culture man.

Counts of fungus colonies from soil do not therefore represent individuals as in cases of bacteria or yeast. Other viable units responsible may be fresh spores or spores long buried in the soil and only newly brought under favorable growth conditions. There are also many types of thick-walled "resting" cells or group of cells produced by various species, which grow in such cultures.

Molds for the most part are definitely aerobic; hence develop in greatest numbers upon decaying vegetation just at or below the surface. If roots are abundant, or if there are masses of plant material plowed under, molds follow the food materials into the soil even though access to air is greatly reduced. A comparatively few species actually develop successfully in the deeper areas without apparent provision for distributing their spores above the soil surface.

Mold hyphae in the soil follow the pores between the inorganic soil particles often adhering rather firmly, where enzymic attack upon mineral constituents is possible. They usually follow and destroy the living or dead root systems of the plants or, in cultivated land, the fragments of plant tissue wherever found. The parasitic root-rots have been traced as following the roots of crop plants as far as 4 feet into the earth.

It has already been indicated that molds (fungi) in some form appear in every study as a part of the soil population and participate in many of the decomposition processes which return organic materials toward useful plant food distributed in the soil. Certain general facts of mold structure must be listed: Molds as seen in the culture laboratory are masses of threads (hyphae) organized into characteristic aggregates called mycelia and usually appear in colonies at or near the surface of the nutrient. The hyphae consist of cells, mostly cylindrical, placed end to end. A hypha produces new cells at one or both ends or by the component cells dividing to make new cells which lengthen. The mold is not motile. It enlarges and spreads in the substratum by lengthening its hyphae and it is usually immersed in

the nutrient or lying on it; hence each cell gathers its own nutrients in the simpler forms. Translocation occurs in the more highly organized species. Such a colony may be torn to short hyphal pieces and each piece will reproduce the colony. Normal reproduction is by some type of spores. In its simplest form a hyphal branch assumes a more or less vertical position, thrusts its end into the air and produces a spore or a group of spores by some process characteristic of the species. Although there are exceptions, the molds we see rarely produce spores below the surface of liquid or within compact masses of a substratum such as soil. Spores as a means of dissemination are set free or discharged into the air.

Microbial decomposition of organic remains is not a simple culture process. There is ample culture record to show that such materials carry with them to the soil large numbers of viable organisms representing a wide variety of not only species but genera, as well as larger and diverse groups of microorganisms. The soil is already well supplied with organisms. Green material plowed under dies slowly, the carbon dioxide of plant respiration floods the soil quickly. Large numbers of organisms of many kinds attack the dying and dead material. Such fabulous numbers¹⁶ as are shown in the green manure columns of Table 3-3 develop in the first few days.

For our purpose here we may look at Tables 3-4 and 3-5 given by Waksman²⁰. In Table 3-4 he presents routine determination of certain organic components in six different types of plant material. In Table 4-5 he gives routine analyses of the residual organic matter extracted from six different

TABLE 3-4

	Young rye	Mature wheat straw	Soybean plants	Mature cornstalks	Young pine needles	Mature oak leaves	Ave.
Ether soluble	2.35	1.10	3.80	5.94	7.65	4.01	4.14
Water soluble	29.54	5.57	22.09	14.14	13.02	15.32	15.35
Hemicelluloses	12.67	26.35	11.08	21.91	14.68	15.60	17.01
Celluloses	17.84	39.10	28.53	28.67	18.26	17.18	24.93
Lignin	10.61	21.60	13.84	9.46	27.63	29.66	18.93
Protein	12.26	2.10	11.04	2.44	8.53	3.47	4.93
Ash	12.55	3.53	9.14	7.54	3.08	4.68	6.75
Total accounted	97.82	99.35	99.52	90.10	92.85	89.92	

TABLE 3-5. CHEMICAL NATURE OF THE ORGANIC MATTER EXTRACTED FROM SOILS OF TABLE 3-4

No.	Ether soluble	Alcohol soluble	Hemi-cellulose	Cellulose	Lignin	Protein
4	3.56	0.58	5.44	3.55	43.37	33.78
6	4.71	1.53	8.60	5.22	40.81	34.74
16	0.80	0.82	5.53	4.12	41.87	37.35
18	1.02	0.88	6.96	3.50	42.05	33.25
21	0.46	0.84	8.54	2.83	42.83	33.36
29	0.62	0.61	8.21	3.64	49.29	30.38

soils. The corresponding components vary markedly in the different plant material but two striking similarities appear in the residual material—the lignin series falls into the range of 40 to 49 per cent in all cases and the proteins ($n \times 5.35$) between 30 and 38 per cent; the water-soluble substances are mostly gone, even the cellulosic fractions are depleted! In short, the microorganisms have broken down all of the easily decomposed materials and left the more difficult ones to slowly decompose, while apparently microbial nitrogenous materials fall in the resistant class. Disregarding exact percentages the general finding has been repeated in other research reports. Thus we are justified in concluding that, however numerous the types of soil may be, the decomposition of organic remains by the soil organisms is a universal process wherever soils are found. Conn found the active bacterial factors to be fairly universally present. Thom has reported certain series of fungi to be equally universal. Identity is not claimed but general agreement of end results and agents producing them is clearly indicated.

Actinomycetes

Conn² in his elaborate study of the micropopulation of the soils of New York State reported actinomycetes as forming 12 to 15 per cent of the organisms found in his cultures. Others have reported them as abundant in all soil populations studies. The actinomycetes are definitely filamentous; hence in laboratory culture they form mats or knots of fine filaments or hyphae and usually chains of spores, but the individual hyphae and spores show so nearly the measurements of bacteria that they have been studied by bacteriologists. Recent research (Couch) places them nearer to bacteria than to fungi. Many of the species grow so slowly in laboratory culture that they have been frequently counted among the bacteria without recognition of their true character. Like most fungi, they rarely fruit while within fluid or in closely packed solid substance. Careful search with the microscope and by culture failed to show extensive participation by any actinomycetes in the rotting of green stuff plowed under^{7, 16}.

Microscopic study of soil particles often shows fine granules which are surrounded by basket-like networks of very fine thread-like hyphae. Spores are difficult or impossible to demonstrate within compact masses of soil. Positive identification with the microscope has not been possible but the fine hyphae of this group never seem to hold clumps of soil together as do the courser hyphae of the molds or especially that of the mushroom. Actinomycetes with innumerable spores have been seen in more or less loose or open organic masses buried in the soil. Like molds, spores are rarely produced unless there are actual open spaces.

Waksman and his co-workers report these organisms, or at least some spe-

cies of them, as attacking and further decomposing humus products which are residues of other rotting processes, especially in the deeper layers of the soil. Other studies find them abundant in primary decomposition of plant tissue above ground. The odor of freshly plowed soil has been attributed to them. They are definitely responsible for the musty odor of grain and hay that has been wet. Manifestly then, they are cosmopolitan, almost omnivorous, and appear wherever rotting plant tissue is found either above or rather deeply buried in the soil. Their significance in the soil is not their participation in rapid rotting processes, or their rate of multiplication, but their persistence throughout the various levels and gradual decomposition of the degradation products left by other organisms.^{19, 20, 21}

Antibiotics from Actinomycetes. The species and varieties of the very common genus *Streptomyces* have produced a wide range of antibacterial products including Streptomycin, Aureomycin, and Terramycin, which are among the most important antibiotics in the world markets. Some of the series are very poisonous. This field was first exploited by Waksman and his colleagues but more recently by many investigators of antibiosis. There is a very great accumulation of literature in this field.

Soil Algae

In water-soaked areas, surface mats of algae are very common, especially as seasonal developments. There is some indication that on acid soils the strictly green (*Chlorophyceae*) forms predominate; in neutral to alkaline soils blue-green (*Cyanophyceae*) species are most abundant. Such developments are well known in the field but no data as to their participation in soil processes are available. In the same studies, representatives of two genera *Chlorella* and *Scenedesmus* have appeared to survive and apparently to multiply to some extent, several inches below the surface, hence independently of sunlight.

Chlorella has been found capable of rapid development in artificial cultures and is presently being studied in various laboratories for its biochemical properties. Some have even claimed that it may prove a source of feed for stock or even food for man. Researches in the field have only started.

Protozoa

Protozoa (1-celled animalculae) have been occasionally reported from soil by zoologists over the past century. The soil microbiologists in their studies of soil population began to give special attention to protozoa shortly after 1900. Although workers in several countries contributed, reports from Rothamsted^{3, 12} in England and from the New Jersey Experiment Station¹⁸ will be cited here.

Soil protozoa are aquatic, usually motile, mostly aerobic, and feed on

organisms smaller than themselves, largely bacteria. Few if any are reported more than 12 inches below the surface of the soil. Dependent on soil water, they are found in the pores of the soil. The species found must necessarily be of such a size and consistency as to permit them to move freely in the pores (Sandon) since they are dependent on the soil water to keep their bodies wet. The further limitation that such organisms must be able to survive long periods of drought restricts the species found to those which can pass quickly into the cystic state, in which inactive cells are encased in chitinous or other almost impermeable walls.

Numbers. In the Rothamsted reports the protozoa were found to multiply with great rapidity in following similar multiplication of the bacteria upon which they feed. Consequently they disappear (die or become cysts) when the bacteria stop rapid multiplication. Working on a similar experiment with green manure Humfeld reported 60 protozoa to the gram in his undisturbed soil, 3,000 to the gram in the soil to which green manure was added, and 60,000 in the rotting green manure covered by soil on the 4th day. The numbers were 60 again after 56 days.

Fellers and Allison⁴ working in New Jersey compared the protozoa of the soil with those of the fresh waters of the state and found that the soil species were identical with certain free-living species in the lakes and ponds. The soil water was obviously continuous with the free water lakes and ponds and it was therefore concluded that the same species might migrate in either direction. Such species when found in the soil would be in active condition only when water was abundant and would then pass into cystic form for the dry periods.

In their study, Fellers and Allison isolated 104 species from soil in New Jersey, of these 51 were ciliates, 35 flagellates, 12 rhizopods, and 4 helizoans. In most of their soil samples only a few species appeared.

Further studies would be needed if more than occasional significance is to be placed upon the protozoan flora of soils in general.

Animal Groups

Nematodes are constantly encountered in cultures from soil. These worm-like organisms become visible with the hand lens, or, some of them to the experienced observer's naked eye. They are active factors, primarily at or near the soil surface. There are many genera and numerous species varying from obligate parasites of root crops, which pass up at intervals between susceptible crops as cysts, to voracious saprophytes which seem almost omnivorous.

There are a whole series of small animals near the status of the microscopic which share with the bacteria, molds, and actinomycetes the destruction of organic remains at or near the surface of the soil. Any one of many

such forms may appear in cultural study samples, especially where aliquots from mixed samples have obliterated visible structures.

Wherever organic remains accumulate in masses, mites (Acarina) (again close to the visible series) appear. They are referred to here because they are frequently present in cultures and because they have not been recognized by workers who failed to make constant use of the compound microscope.

Strenzke¹⁷ has recently described 240 species and subspecies of them.

Myxomycetes: Amoebae and Amoeboid Cells

Thom and Raper report that soil and rotting vegetation in the field commonly carry amoeboid organisms. Amoebae as protozoan species have been reported by the Rothamsted workers without recognizing the presence of the myxomycete series. In the American work, the myxomycete forms outnumber greatly the strictly animal organisms. In controlled culture the amoeboids multiply rapidly, develop plasmodia and commonly fruit as identifiable myxomycetes. Such fruiting areas in lawns or waste places often show thousands of spore masses. No adequate survey has yet been reported.

The microbial populations have been thus presented as definitely more or less under man's control. Microorganisms constitute a rather large and quite heterogeneous population, relatively inactive in fallow soil but capable of tremendous activity if cultivation and fertilization, coupled with favorable reactions, temperatures and moisture conditions occur. Such activities may be extremely local, resulting from a disturbance affecting a minute area, or widely extended when large areas are subjected to broad cultural operations or climatic or seasonal influence (rain, heat, cold, etc.). Every group of organism is capable of immediate response in the form of rapid production of great numbers of cells which participate in some decomposition process. Commonly such decomposing masses are so localized that the vast majority of the organisms concerned in the process die at its completion.

The Nitrogen Problem

Crop plants require nitrogen but use it mostly as nitrates and ammonia. Plant and animal remains are not used directly—hence rotting processes are necessary. The ordinary organisms of decomposition leave the last steps toward plant food uncompleted. Winogradsky is credited in the early 1890's for developing our first definite information about the nitrifying bacteria even though he defined their life history in rather fantastic terms. Waksman in his "Principles of Soil Microbiology"¹⁸ abstracts an enormous literature in this field.

Winogradsky's discoveries were hailed at once as a solution to the practical problem of testing and securing soil fertility. Routine tests for nitrifying power were applied to samples from thousands of locations. However in-

teresting the data obtained by such sampling, such testing failed to correlate satisfactorily with results in the field; hence the procedure was abandoned. The nitrifying organisms constitute a universally present group in the soil flora and contribute to the bewilderingly complex processes which maintain crop production.

Indications that organisms other than the series described by Winogradsky contribute to nitrification have recently appeared. Schmidt⁸ working in Minneapolis has reported nitrification by a strain from the universally distributed *Aspergillus flavus* series. It is entirely probable that other organisms play a similar role.

Another phase of the problem concerned the atmosphere as the exhaustless source of the needed Nitrogen. At that time nitrogen was the expensive component of all commercial fertilizers: hence every suggestion that even offered a promise was early followed up.

Symbiotic Nitrogen Fixation

Legumes had been associated with soil improvement for ages. In 1838 Boussingault showed that in some way they added nitrogen to the soil. In 1886 Hellriegel and Wilfarth proved that the nitrogen was taken from the air by bacteria located in nodules upon the legume roots. In 1888, Beijerinck isolated the organisms responsible which were placed in the genus *Rhizobium*. Hundreds of workers have confirmed and extended our knowledge of rhizobia in relation to legume crops. Special strains have been developed for the various species of Leguminosae. The United States Department of Agriculture is now (1954) said to maintain 1200 strains to cover the needs of the nation's legume crops. Commercial cultures have been developed and distributed for the inoculation of millions of acres. Fred, Baldwin and McCoy⁵ monographed the entire subject in 1932.

The situation may be summarized by saying that the rhizobia are so well adjusted to symbiotic life in legume roots that their presence in the proper variety for the particular legume commonly yields the striking result shown in Figure 3-1. The organism may be applied to the seed by suspension in water and successfully introduced where it was absent previously. Thus far, in spite of claims for other organisms, the legume nodule species is the only beneficial organism that has been profitably introduced in all countries where tests are reported.

Nitrogen Fixation by Free-Living Organisms: Azotobacter

Beijerinck in 1901 described the genus *Azotobacter* and two species, *A. chroococcum* and *A. agile*. It is an aerobic genus whose species can take nitrogen from the atmosphere for their metabolism, to contribute directly to soil organic matter. Laboratory tests (*in vitro*) prove that the members of this



Figure 3-1. Field test with Austrian winter peas, check inoculated by L. T. Leonard.

genus can grow in solutions free from organic nitrogen. Field studies showed that they are widely distributed. As a result there developed a large literature upon *Azotobacter* as a factor in soil fertility. It was hailed as solving our problem. Subsequent studies proved that they do not appear in acid soils, and that where ample supplies of organic nitrogen are present, free nitrogen is not fixed. Studies by Gainey and others over wide areas failed to show such enormous numbers in the field as would be needed to add greatly to soil organic matter. Further, it has not been successfully introduced or induced to multiply. Their total contribution may be material at times but for the most part such measurable significance as was inferred from laboratory results has not been confirmable by actual surveys of soil. In brief then, we note its presence as an organism of nearly world-wide distribution and an interesting biochemical character as well as its very minor importance to agriculture. Meanwhile the chemists solved the problem by practical fixation of atmospheric nitrogen in factory quantities.

Sulfur, Iron, Magnesium, etc.

There are many reports covering phases of the function of soil organisms in the transformation of sulfur compounds. Many of these consist of laboratory tests under controlled conditions which have proved that special organisms isolated from soil are capable of transforming the sulfur present either as the pure element or as a compound into a form which is available for plant food. Similarly, the other elements, especially iron, have been extensively studied. Common observation had noted the disappearance of

such products. The capacity to produce particular changes has been demonstrated in pure culture as a result of organism after organism selected from the multitude of species present.

The inference has often been drawn that the proved ability of the single organism tested to bring about a particular change accounts for what occurs in the soil. Further investigations have tended to discredit the idea that transformations depend on special species which produce the needed changes by separate steps, however significant that species may be. Actually, no such steps can be safely postulated.

Inactive Organisms Found in Soil

Great numbers of species of microorganisms reach the soil without becoming active in soil activities. Some die quickly. Many survive for periods determined by their ability to find protection or to pass into resistant spore forms. Exhaustive study of the survival of animal, plant and human disease germs has established the necessary precautions against certain infections: much remains to be done. Academic research has disclosed many interesting organisms whose part in soil processes is doubtful since they are known only as laboratory curiosities thus far. Only two of these species will be noted here.

Tetanus. The tetanus organism (lockjaw) is present in practically all soils, and hence justifies presumption of infection in any deep wound contaminated with dirt, necessitating the immediate use of antitoxin. The spores only are found; the organism survives in the soil but is not active there. Its principal source is in the manure of warm-blooded animals.

Botulism. Widespread occurrence of deaths from botulism over a period of years led Dr. K. F. Meyer of the University of California to survey the soil as a source of infection. In all, more than 4,000 samples from the United States and several foreign countries were cultured by an enrichment technique designed to demonstrate the organism even when present in very small numbers. Of these samples 831 showed at least one type of *Clostridium botulinum*. Questioned carefully as to the significance of this organism in the soil, he insisted that under conceivable but rare conditions a spore of this species might germinate, produce 2 or 3 bacterial cells and return to the spore form. There is no indication that this clostridium actually multiplies in the soil or participates in any soil process. The importance of finding it there remains as a constant warning of soil contamination in animal or human food.

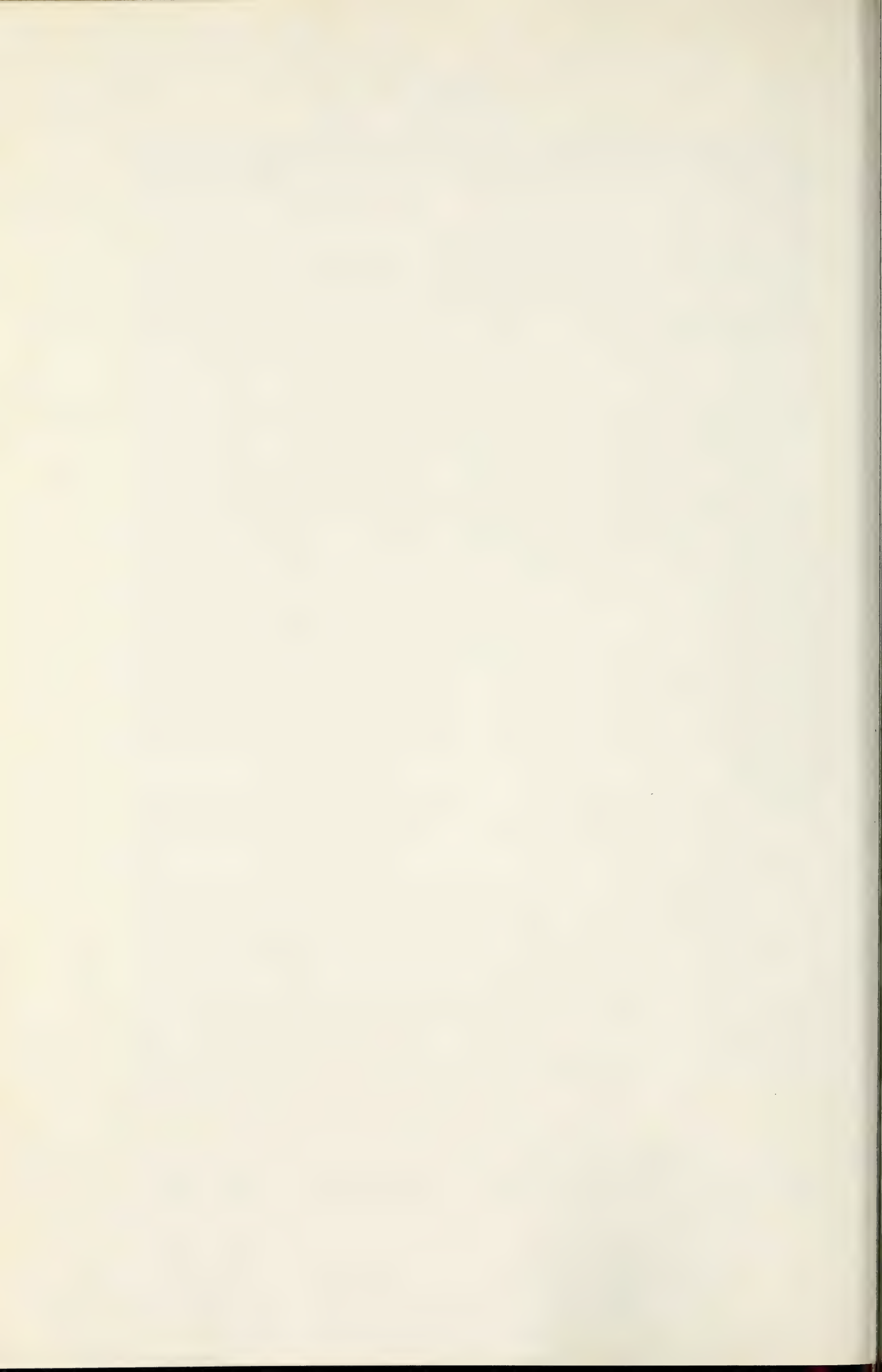
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The literature of soil microbiology is very extensive both in the discussion of microorganisms and the biochemical description of their activities. Such

contributions appear in many languages. The whole period of development up to the date of publication is covered in the monographic manner by Waksman¹⁹."

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4 . FERTILIZERS

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This chapter presents information on the composition and properties of the materials commonly used for soil improvement, compilations of statistics on their preparation and use, and a brief discussion of the chemistry involved. The data on composition were compiled from many publications, such as those of Burchard¹¹, the California Department of Agriculture¹², Clarke¹⁵, and Lindsey *et al.*³⁶ Consumption statistics were derived from state fertilizer tonnage reports, the United States census of agriculture, and surveys made by the author and his former associates in the U. S. Department of Agriculture (⁷¹ and similar articles annually in the June number of the fertilizer trade journals since 1946).

Manures

Manure is partially decomposed organic matter, such as animal excrements, sewage sludge, compost and peat. Most of the manure applied to farm land is derived from animal excrements mixed with litter.

Animal Manures. The quantities of animal excrements produced annually and their average nutrient contents are shown in Table 4-1.

Dung of animals consists principally of bacteria, humus, and the undigested portion of food, largely cellulose and lignin. The nitrogen, phosphorus, and potassium in feces are present almost entirely as insoluble compounds that must be decomposed before the nutrients are available to plants. Urine, on the other hand, has all its nutrients in immediately available forms. From 60 to 90 per cent of the urinary nitrogen is present as urea. The urinary excretions of poultry are mixed in a concentrated form with the feces. The average farmer adds about one ton of litter (straw, shredded corn stalks, sawdust, or peat moss) to every four tons of cattle manure produced. These materials absorb up to several times their own weight of urine, and some free ammonia.

TABLE 4-1. AVERAGE ANNUAL PRODUCTION AND PRIMARY NUTRIENT CONTENT OF SOLID (S) AND LIQUID (L) EXCREMENTS OF MATURE ANIMALS^a, AND AVERAGE QUANTITIES OF MANURE SPREAD ON CROP LAND PER ANIMAL ANNUALLY IN ILLINOIS AND INDIANA^b

Kind	Production		N		P ₂ O ₅		K ₂ O		Manure Spread (Tons)
	S (Tons)	L (Tons)	S (%)	L (%)	S (%)	L (%)	S (%)	L (%)	
Horse	6.5	1.5	0.50	1.20	0.30	Tr	0.24	1.50	5.0
Cattle	8.9	4.0	0.32	0.95	.21	0.03	.16	0.95	6.5 ^c
Sheep	0.46	0.27	.65	1.68	.46	.03	.23	2.10	0.3
Hog	1.10	.64	.60	0.30	.46	.12	.44	1.00	.35
Turkey	0.17		1.31		.71		.49		
Hen	.07		1.48		.96		.47		.02

^a Data for mammals from Salter and Schollenberger⁶⁹; for poultry from White, Holben, and Richer⁸⁰.

^b Adapted from Ross⁶³, and Bauman and Fitzpatrick¹⁰. Includes litter. Believed to represent roughly the entire area from New Jersey to Minnesota and Iowa, inclusive.

^c Dairy cattle. The average with beef steers is somewhat less.

Only a fraction of the nutrients present in animal excrements can be used on crop land. Even in the North from one-fourth to one-half of the excrements are dropped in pastures, and in the South and on the open ranges of the West little or none is collected. The percentage utilization of the total excrement production on crop land varies from 56 in New England to 0.9 in the West South Central Region⁵¹. The average for the United States is 15 per cent. The total production of excrement plus the weight of litter used in 1947 was 1,370,000,000 tons, of which 206,000,000 tons,* containing 1,227,000 tons of nitrogen, 783,000 tons of phosphoric oxide and 1,081,000 tons of potash, were applied to crop land. About 65 per cent of the total consisted of cattle, 15 per cent of hog, 12 per cent of horse and mule, 5 per cent of poultry, and 3 per cent of sheep and goat manure.

Fermentation of moist manure at summer temperatures is rapid. Cellulose and pentosans are converted into humus, and protein and urea into ammonia. Under favorable conditions one-third of the total nitrogen is finally converted to nitrate. Under farm conditions from 40 to 60 per cent of the nitrogen in manure is lost either from volatilization of ammonia, leaching, or other causes. The average loss of nutrients in the northern states is estimated to be: N and K₂O, 50; P₂O₅ and CaO, 20; MgO, 25; and SO₃, Cu, Mn and Zn, 30 per cent. Exclusion of air prevents overheating, encourages the acid-forming type of fermentation, and thus minimizes loss of nitrogen.

* Revised. The original data for Rhode Island and Utah have been changed to 320,000 and 700,000 tons, respectively.

TABLE 4-2. COMPOSITE^a ANALYSES OF ANIMAL MANURES (PER CENT)

Constituent	Eastern barnyard	Cattle	Horse	Sheep	Swine	Chicken
N	0.50	0.53	0.55	0.89	0.63	0.89
P ₂ O ₅	.37	.29	.27	.48	.46	.48
K ₂ O	.52	.48	.57	.83	.41	.83
Na ₂ O	.11	.06	.10	.20	.18	.20
CaO	.48	.40	.38	.53	.27	.53
MgO	.24	.19	.18	.22	.05	.22
R ₂ O ₃	.96	.07	.26	.60	.49	.60
CuO	.0003	.001	.001	.001	.0002	.0008
MnO	.17	.004	.004	.004	.001	.0037
ZnO		.002	.003	.003	.0007	.0026
Cl	.13	.03	.08	.08	.03	.08
SO ₃	.10	.09	.09	.14	.07	.14
B ₂ O ₃	.016	.005	.005	.005	.0015	.0049
SiO ₂ and acid insol.	5.88	.72	3.45	1.75	4.21	1.75
Org. matter	20.07	16.74	27.06	30.70	15.50	30.70
Moisture	71.89	81.33	68.85	64.82	77.56	64.82
Ash	8.78	2.06	6.70	4.72	6.02	4.72

^a Averages of large numbers of determinations⁴⁷.

Composition of the principal types of manure is summarized in Table 4-2. The United States weighted average for all kinds is: N, 0.66; P₂O₅, 0.40; and K₂O, 0.52 per cent. Manures contain significant quantities of vitamins and hormones, such as thiamine, biotin, pyridoxine and others⁶⁶.

More details on farm manures are given by Van Slyke⁷⁷; on cattle manure by Wells and Dunbar⁷⁹ and on poultry manure by White, Holben, and Richer⁸⁰.

Sewage Sludge. The average person excretes annually 10 pounds of nitrogen, 3.3 pounds of phosphoric oxide, and 1.6 pounds of potash. Mixed excrements from privy vaults is called night soil and the digested solid matter from sewage disposal is sewage sludge. In 1950, 46 American cities disposed of 320,340 tons of digested sludge (65 per cent moisture basis) and 164,000 tons of dried sludge for fertilizer use. For the composition of these manures see Tables 4-3, 4-13, 4-14 and 4-15.

Compost. Organic matter high in cellulose or pentosans, provided it contains at least 1.2 per cent nitrogen on the dry basis, rots under slightly alkaline aerobic conditions to form compost. Straw, sawdust, peanut hulls and similar materials do not ordinarily contain enough nitrogen, but addition of about 100 pounds of calcium cyanamide, or its equivalent in nitrogen and calcium, per ton promotes good compost production¹⁸. 150 samples of compost averaged: N, 1.24; P₂O₅, 1.01; K₂O, 1.24; CaO, 4.43; organic matter, 41.61; moisture, 46.64 and ash, 11.36 per cent.

TABLE 4-3. AVERAGE PERCENTAGE COMPOSITION OF MANURES

Constituent	Sewage sludge ^a	Night soil	Peat ^b	Seaweed ^c	
				Atlantic	Pacific
N	0.76	0.95	1.86	1.50	0.99
P ₂ O ₅	0.57	1.67	0.25	0.99	0.57
K ₂ O	.12	0.40	.16	4.92	13.68
Na ₂ O	.23	.20	.14	4.77	3.05
CaO	1.21	.84	1.58	2.90	1.63
MgO	0.17	.49	0.60	1.23	1.15
R ₂ O ₃	2.92	2.24	.73	0.68	
CuO	0.14	0.001	.075	.03	
MnO	.17	.003	.025	.01	
ZnO	.20	.004	.005	.01	
Cl	.08	.06	.11	3.17	11.24
SO ₃	.16	.54	.64	3.47	2.39
B ₂ O ₃	.001	.007	.021	0.058	
I				.23	0.25
Acid insoluble	11.94	.18	4.67	3.90	
Organic matter	16.33	17.74	68.88	64.57	53.73
Moisture	63.93	74.07	19.62	9.39	14.24
Ash	19.74	7.19	10.92	28.32	42.00

^a As given away at sewage disposal plants. Pearse *et al.*⁵⁹, Rudolfs and Gehm⁶⁸ and many others.

^b Anderson, Blake and Mehring⁷.

^c U. S. Senate⁷⁶, Gardner²³, Merz⁵⁴ and others.

Peat. Vegetation decomposed under water forms peat. In 1950, consumption consisted of 130,723 tons of domestic and 124,861 tons of imported peat. Consumption by uses was: soil improvement, 161,000; fertilizer filler, 56,000; litter, 31,000; others, 8,000 tons. Moss peat can absorb from 10 to 20 times, and reed and sedge peat from two to five times their own weight of water. From one-fifth to one-half of the organic matter consists of humus, 3 to 15 per cent is cellulose and 8 to 25 per cent is hemicellulose. The pH of moss peat varies from 3.2 to 5, and of reed and sedge peat from 4 to 6⁷.

Seaweed. This manure, gathered from the beaches, is a mixture of several species of partly dried seaweed, shells, remains of fish and other organisms, sea salt, and sand. The quantities used decreased from 300,000 tons in 1880 to around 50,000 tons in 1950. Seaweed is free of objectionable microorganisms but does not form humus, inasmuch as it decomposes completely to gases and water-soluble compounds.

Liming Materials

The quantities of the various materials used to sweeten the soil are presented in Table 4-4. All are compounds of calcium, magnesium, or both.

TABLE 4-4. UNITED STATES CONSUMPTION^a OF LIMING MATERIALS BY KIND (SHORT TONS)

Calendar year	Limestone	Burned lime	Hydrated lime ^b	Marl ^c	Shells ^d	Blast furnace slag	Other ^e	Total
1850		280,000		500,000			6,000	786,000
1860		310,000		600,000			7,000	917,000
1870		340,000		800,000			8,000	1,148,000
1880		390,000		1,120,000			9,000	1,519,000
1890		435,000		172,054			70,000	677,000
1900		530,000		67,000			82,000	679,000
1910	174,290 ^f	265,057	320,819	65,000	42,000	500	56,000	923,666
1920	1,864,260	241,376	148,981	97,487	40,000	2,000	259,000	2,653,104
1930	2,962,641	77,900	274,075	81,186	25,206	10,000	77,288	3,498,296
1935	2,371,927	90,974	204,616	421,314	52,173	30,000	120,785	3,291,789
1940	12,203,946	185,535	221,499	482,869	125,918	50,000	163,848	13,433,615
1945	20,836,101	136,047	272,286	443,834	140,000	65,184	465,919	22,357,403
1950	25,266,600	121,500	213,500	469,600	58,207	83,297	323,096	26,535,800
1951	25,089,300	138,000	201,700	488,000	77,817	66,060	524,123	26,585,000
1952	24,948,600	130,000	201,400	540,600	75,361	85,817	433,322	26,415,100

^a 1850–1920, Mehring⁴⁰; 1930–52; National Lime Association⁵⁶. The data on shells were obtained from the U. S. Fish and Wildlife Service, and those on blast furnace slag from the National Slag Association. Does not include fertilizer filler nor approximately a million tons used annually in the manufacture of feeds, and fungicides, or as poultry grit.

^b Included with burned lime, 1850–1900.

^c Both farm dug and commercial.

^d Ground oyster, clam, and fresh-water mussel shells. Quick lime made from shells is included under burned lime.

^e Includes by-product lime, chats, egg shells, carbide residue, lime kiln ashes, and phosphorus furnace slag, but not basic slag.

^f 1911.

The rapid increase in consumption after 1935 was due to the Soil Conservation Program. It reached a peak in 1947 with 30,282,902 tons. More than two-thirds of the total is consumed in the North Central Region. Practically none is used in the Western half of the country, except for small tonnages in the Pacific Northwest. The new “Versenate” method¹³ of titrating both calcium and magnesium in the same aliquot is just as accurate, much more rapid, and easier to carry out than the methods of analysis widely used at present.

Limestone. Although not used as a soil amendment until 1902, ground limestone now constitutes about 95 per cent of the total. It is essentially calcium carbonate, but it usually contains magnesium carbonate. When the latter supplies 10 to 39.9 % of the neutralizing value it is dolomitic limestone, and when 40 or more per cent it is called dolomite.

It is not generally economical to use limestone containing less than 80 per cent of calcium carbonate equivalent*. The Association of American Fertilizer Control Officials⁸ requires that ground limestone should pass a 10-mesh sieve and at least 50 per cent should pass a 100-mesh sieve. 653 samples reported by State Control Officials from 1940 to 1949 averaged only 1.71 per cent coarser than 20 mesh and 74.6 per cent finer than 100 mesh.

Chemical data on agricultural limestones are summarized in Table 4-5. Analyses of deposits in many states are given by Burchard¹¹.

Dolomite. The pure mineral consists of equimolecular amounts of calcium and magnesium carbonates, with 21.83 per cent magnesium oxide. The statistics on production and use are combined with those of ordinary limestone. Most of the limestone used in the southeastern states and Wisconsin is really dolomite. The weighted average magnesia content of all dolomite used in the manufacture of mixed fertilizers in 1945 was 19.63 per cent⁴⁵. Dolomite is also a by-product of lead and zinc mining. The material from Joplin, Mo., commonly called chats, averages: CaO, 29.6; MgO, 15.47; MnO, 0.7; PbO, 0.5, and SiO₂, 4 per cent.

Lime. When limestone, oyster shells, or other calcium carbonate is heated above 899°C, it decomposes as follows: $\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$. If this burned lime is exposed to cool damp air it slakes to again form the carbonate, mixed with hydroxide. Shell lime slakes more rapidly than stone lime, because it has more surface per unit of mass. 489 samples of stone lime and 23 samples of shell lime averaged: CaO, 74.19 and 64.75; MgO, 9.31 and 0.46; CO₂ 3.77 and 10.80, and water of constitution, 4.54 and 16.32 per cent, respectively.

Hydrated Lime. Lime combines with water to form hydrated lime, Ca(OH)₂. 983 samples averaged: CaO, 62.52; MgO, 9.79; CO₂, 4.82; and water of constitution, 18.28 per cent, respectively.

Marl. Calcium carbonate is precipitated on the bottoms of certain swamps or lakes by biological action to form chalk-like beds of marl. Deposits are being exploited in more than a dozen states (see Table 4-5 for its composition). Greensand marl is potassium-iron silicate, which is used as a source of potash near the deposits in New Jersey. It is not a liming material.

Shells. Ground oyster, clam, fresh-water mussel, fossil, and egg shells are all regularly used as soil amendments in different parts of the country where they are economically available. Most samples contain over 95 per cent of calcium carbonate on a dry basis. Fresh mollusk shells also contain around 2 per cent and egg shells from bakeries and drying plants approximately 7 per cent of organic matter. Egg shells contain: N, 1.2; P₂O₅, 0.6, and K₂O, 0.3 per cent, respectively.

* CaCO₃ equivalent is the percentage of CaCO₃ plus 1.19 times that of MgCO₃.

TABLE 4-5. COMPOSITE ANALYSES OF LIMESTONE, MARL AND BLAST FURNACE SLAG

Constituent	Limestone ^a				Marl ^b	Slag ^c			
	No. of Samples	Min. (%)	Max. (%)	Mean (%)	Mean ^d (%)	No. of Samples	Min. (%)	Max. (%)	Mean (%)
N					0.06				
P ₂ O ₅	593	0.00	2.59	0.11	.38	8	0.007	3.21	1.69
K ₂ O	521	.01	1.07	.29	.86	65	.08	2.26	0.59
Na ₂ O	521	.01	0.88	.08	.47				
CaO	1892	30.12	55.74	43.62	42.12	316	26.40	50.80	41.02
MgO	1628	0.05	23.77	6.01	0.65	316	1.49	19.43	6.34
Al ₂ O ₃	828	.01	6.05	0.87	2.12 ^e	310	0.80	20.27	12.13
Fe (metallic)						11	.24	1.24	0.66
FeO						303	.20	4.15	1.17
Fe ₂ O ₃	828	.01	9.84	.66	^f				
CuO	17	.0005	0.011	.0052		32	.0003	0.0022	0.0013
MnO	489	.0001	1.98	.34	0.31	341	.09	2.40	1.33
PbO	26	.0000	0.32	.018		26	.0000	0.0022	0.0003
TiO ₂	47	.000	.40	.096		53	.18	1.60	.44
ZnO	25	.0001	.019	.057		26	.0002	0.0030	0.0010
CO ₂	843	32.22	47.56	40.68	27.13				
Cl	355	0.0002	0.04	0.019					
S	504	.000	.37	.10		303	.05	4.16	1.40
SO ₃	98	.00	2.92	.11	0.66				
B ₂ O ₃	3	.000	0.018	.01	.0015	66	.022	0.0708	0.040
SiO ₂	918	.00	31.84	5.62	12.46	284	28.26	41.29	33.85
Organic matter	516	.01	5.91	0.45	2.97				
Moisture	704	.02	5.85	.21	9.80	335	0.00	0.65	0.31

^a Burchard¹¹, Clarke¹⁵, Miller⁵⁵ and analysis bulletins of many states.

^b Woll⁸² and many others.

^c Chichilo and Whittaker¹⁴ and National Slag Assoc.⁵⁷.

^d Two determinations each for MnO and B₂O₃, 4 for Na₂O, 7 for organic matter and 17-175 for the rest.

^e R₂O₃, 29 determinations.

^f Included with Al₂O₃.

Slags. The various slags used as soil amendments are all essentially calcium silicate (Table 4-5). Although 30,000,000 tons of blast furnace slag are produced, only about 80,000 tons are used annually as a liming material. The Tennessee Valley Authority, in the year ended June 30, 1950, disposed of 185,139 tons of slag obtained as a by-product of the electric furnace production of phosphorus. Phosphorus-furnace slag contains: P₂O₅, 0.93-2.3;

CaO, 42.6–54.3; F, 2.16–3.20; and SiO₂, 35.8–42.3 per cent. Basic slags are discussed under fertilizers.

Commercial Fertilizers

The Industry. The American fertilizer industry began in Baltimore, Md., in 1849. Until about 25 years ago, its only manufactured products were superphosphate and mixed fertilizers. Many different ingredients were used in the latter, but all except superphosphates were either natural minerals, by-products of other industries, or imports.

Today the fertilizer industry is a chemical industry and all the necessary raw materials are produced in the United States. The estimated production

TABLE 4-6. PRODUCTION, FOREIGN TRADE AND CONSUMPTION OF COMMERCIAL FERTILIZERS

Calen- dar Year	Production ^a		Imports ^b		Exports ^b		Shipments ^c	
	Quantity (1,000 tons)	Value (million dollars)	Quantity (1,000 tons)	Value (million dollars)	Quantity (1,000 tons)	Value (million dollars)	Quantity (1,000 tons)	Value (million dollars)
1859	22 ^d	0.9					150	1
1869	153 ^d	5.8					300	6
1879	727 ^d	19.9					700	25
1889	1,899 ^d	35.5					1,300	44
1899	2,887	46.2 ^e					2,603	71
1904	3,592	63.0 ^e					3,704	103
1909	5,618	111.9 ^e	1,200	26.2			4,821	137
1914	8,432	169.0 ^e	1,700	32.5			7,194	201
1919	8,237	284.5	700	23.4			6,751	402
1925	8,229	195.0	2,541	78.1	1,279	17.3	7,503	281
1929	9,320	222.7	2,587	72.3	1,718	20.4	8,208	277
1935	6,460	120.6	1,574	29.4	1,662	14.8	6,534	178
1939	8,766	161.9	1,622	33.9	1,562	17.1	7,993	245
1945			1,665	41.3	1,023	18.2	14,128	561
1947	17,651	466.5	1,268	43.5	3,119	93.4	17,398	657
1949	18,000 ^d	590.0	1,453	62.7	3,263	92.2	17,928	807
1950	20,000 ^d	658.8	1,913	74.6	3,421	77.0	19,760	888
1951	20,500 ^d	767.6	2,499	101.9	2,582	50.8	21,056	941

^a "Census of Manufactures". Not including secondary products of the fertilizer industry, but including fertilizers produced as secondary products in other industries.

^b 1909–45 "Foreign Commerce and Navigation of the U. S." 1947–51, "Summaries of Foreign Commerce." Where none are given, official data are not available.

^c To consumers. The value is based on delivered to the farm retail prices, and includes government distribution.

^d Estimated.

^e Revised.

capacity of material available for fertilizer as of January 1, 1954, is 2,006,000 tons of nitrogen, 2,667,000 tons of phosphoric oxide, and 1,941,000 tons of potash. Table 4-6 shows the growth and size of the industry.

At the beginning of this century fertilizer mixing plants were concentrated along the Atlantic and Gulf Coasts, but now over 1,000 plants are scattered in nearly all the states. Their locations and other information for each plant are given in the "Farm Chemicals Handbook"¹ and "Commercial Fertilizer Year Book"². More than one-third of the business is conducted by seven large companies with numerous factories, and half of the total by sixteen companies. Many small companies each ship less than 1,000 tons annually, and some only a few tons of small package goods for house plants.

TABLE 4-7. CONSUMPTION^a OF FERTILIZERS AND THEIR NITROGEN, AVAILABLE PHOSPHORIC OXIDE, AND POTASH CONTENTS

Calendar year	Thousand tons				Percentages			
	Fertilizer	N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O	Total Nutrients
1850	53	3	4	1	5.66	7.55	1.89	15.10
1860	164	10	12	3	6.10	7.32	1.83	15.25
1870	321	14	31	4	4.36	9.66	1.25	15.27
1880	753	19	70	13	2.52	9.30	1.73	13.55
1890	1,390	38	132	31	2.73	9.50	2.23	14.46
1900	2,730	62	246	86	2.27	9.01	3.17	14.45
1910	5,547	146	499	211	2.63	9.00	3.80	15.43
1920	7,296	228	660	257	3.12	9.05	3.53	15.70
1930	8,425	377	793	354	4.47	9.41	4.20	18.08
1940	8,656	419	912	435	4.84	10.54	5.03	20.41
1941	9,607	458	994	467	4.77	10.34	4.86	19.97
1942	10,331	398.6	1,130.8	547.0	3.86	10.95	5.29	20.10
1943	11,734	508.7	1,237.5	642.8	4.33	10.55	5.48	20.36
1944	13,331	634.6	1,405.3	649.0	4.76	10.54	4.87	20.17
1945	14,128	640.9	1,438.8	752.0	4.54	10.18	5.32	20.04
1946	16,166	759.2	1,673.3	853.8	4.70	10.35	5.28	20.33
1947	17,398	835.7	1,775.3	879.2	4.80	10.20	5.05	20.05
1948	17,596	841.3	1,843.1	956.1	4.78	10.47	5.43	20.68
1949	17,928	911.5	1,883.9	1,064.2	5.08	10.51	5.94	21.53
1950	19,760	1,126.0	2,071.8	1,215.3	5.70	10.49	6.15	22.34
1951	21,056	1,265.9	2,090.3	1,412.6	6.01	9.93	6.71	22.65
1952 ^b	22,432	1,422.2	2,199.4	1,581.5	6.35	9.80	7.05	23.20 ^c
1953 ^b	23,413	1,637.1	2,270.8	1,740.2	6.99	9.70	7.43	24.12

^a The data include Alaska, Hawaii, and Puerto Rico, and government distributed fertilizers.

^b Year ended June 30.

^c If materials that are not guaranteed to contain N, P₂O₅, or K₂O, like gypsum, are left out of the computations, this figure becomes 24.05.

TABLE 4-8. CONSUMPTION IN TONS OF FERTILIZERS BY STATES AND REGIONS, SELECTED CALENDAR YEARS, 1880-1950^a

State and region	1880	1900	1920	1930	1940	1950
Maine	5,000	40,000	168,000	195,650	147,520	199,148
New Hampshire	3,000	12,270	17,000	12,000	17,836	28,154
Vermont	4,000	15,500	20,000	16,069	28,742	51,819
Massachusetts	22,000	75,086	61,421	66,621	69,164	94,237
Rhode Island	2,000	6,000	10,000	8,000	11,843	18,231
Connecticut	5,000	35,000	65,000	59,000	62,768	95,180
New England	41,000	183,856	341,421	357,340	337,873	486,769
New York	39,000	247,000	250,000	280,000	397,718	623,008
New Jersey	30,000	66,000	164,821	156,445	183,567	248,998
Pennsylvania	90,000	213,000	332,926	333,715	365,305	628,824
Delaware	6,000	12,000	61,735	43,000	35,506	58,007
Maryland	84,000	151,000	172,410	177,021	161,143	254,221
D.C.	500	1,000	1,000	1,000	1,800	2,097
West Virginia	5,000	25,000	35,400	44,000	71,785	104,833
Middle Atlantic	254,500	715,000	1,018,292	1,036,181	1,216,824	1,919,988
Virginia	55,000	220,000	465,247	449,178	427,132	781,515
North Carolina	65,000	276,238	1,170,440	1,242,036	1,091,159	1,857,351
South Carolina	86,449	292,152	1,098,487	749,230	685,852	953,264
Georgia	152,464	412,755	1,003,053	928,606	782,739	1,231,593
Florida	1,200	33,218	262,061	488,624	532,808	925,308
South Atlantic	360,113	1,234,363	3,999,288	3,857,674	3,519,690	5,749,031
Ohio	15,000	89,000	280,000	327,179	366,211	927,279
Indiana	7,000	58,000	231,791	224,055	257,658	877,483
Illinois	4,000	11,000	45,000	65,818	98,301	1,015,043
Michigan	5,000	15,000	112,616	145,000	166,564	507,100
Wisconsin	4,000	2,500	12,000	51,222	70,521	413,796
East North Central	35,000	175,500	681,407	813,274	959,255	3,740,701

TABLE 4-8—Continued

State and region	1880	1900	1920	1930	1940	1950
Minnesota	1,000	1,000	5,000	16,254	19,421	234,935
Iowa	1,000	1,000	3,500	24,597	15,643	359,748
Missouri	1,000	3,300	92,737	59,810	92,941	482,464
North Dakota			200	1,548	1,800	17,679
South Dakota			200	200	500	6,608
Nebraska			500	1,000	2,200	53,820
Kansas	1,000	700	12,650	6,355	18,000	175,389
West North Central	4,000	6,000	114,787	109,764	150,505	1,330,643
Kentucky	4,500	24,000	88,000	113,992	272,948	578,182
Tennessee	4,000	36,448	98,535	163,909	211,743	534,805
Alabama	35,000	150,000	374,860	644,350	616,808	1,237,859
Mississippi	6,000	98,000	131,084	403,718	233,464	746,621
East South Central	49,500	308,448	692,479	1,325,969	1,424,963	3,097,467
Arkansas	50	3,000	77,550	157,684	117,130	343,454
Louisiana	5,000	31,813	110,765	175,560	157,582	293,586
Oklahoma		100	4,000	6,613	7,679	141,007
Texas	1,000	10,000	55,405	145,218	118,967	598,406
West South Central	6,050	44,913	247,720	485,075	401,358	1,376,453
Montana				1,250	4,500	15,392
Idaho			300	2,100	7,000	51,758
Wyoming				350	2,100	6,701
Colorado	100	500	250	1,200	5,557	43,250
New Mexico	100	200	700	1,787	2,904	18,200
Arizona			500	4,000	7,082	75,976
Utah	100	200	200	800	3,050	25,997
Nevada			30	90	500	1,814
Mountain	300	900	1,980	11,577	32,693	239,088
Washington		400	6,000	21,000	48,867	123,972
Oregon	100	500	6,000	12,000	24,654	86,340
California	2,000	8,000	66,380	142,489	218,964	1,165,941
Pacific	2,100	8,900	78,380	175,489	292,485	1,376,253
Continental U.S.	752,563	2,677,880	7,175,754	8,172,343	8,335,646	19,316,393

^a See first column of Table 4-9 for similar data for the year ended June 30, 1952.

TABLE 4-9. CONSUMPTION IN TONS OF FERTILIZERS AND PRIMARY PLANT NUTRIENTS
BY STATES IN THE YEAR ENDED JUNE 30, 1952^a

State	Fertilizer	Nitrogen	P ₂ O ₅		K ₂ O	Total available nutrients
			Available	Total		
Maine	212,531	12,804	23,342	24,263	25,954	62,100
New Hampshire	21,022	793	2,586	2,735	2,155	5,534
Vermont	56,149	1,186	8,579	9,030	6,035	15,800
Massachusetts	92,079	4,649	8,745	9,216	8,089	21,483
Rhode Island	16,739	876	1,647	1,743	1,506	4,029
Connecticut	87,234	4,575	7,239	8,080	6,926	18,740
New York	634,917	30,360	79,289	82,960	42,128	151,777
New Jersey	264,982	14,123	27,611	29,035	24,116	65,850
Pennsylvania	664,855	25,299	35,096	89,222	52,818	163,213
Delaware	80,387	3,771	8,561	8,964	7,612	19,944
Maryland	296,926	12,112	34,002	37,039	23,138	69,252
District of Columbia	2,541	125	243	249	124	492
West Virginia	99,878	2,512	14,827	15,801	6,913	24,252
Virginia	868,911	33,887	93,422	99,212	71,308	198,617
North Carolina	1,941,179	109,161	163,434	175,723	133,185	405,780
South Carolina	979,131	61,157	81,422	87,455	68,924	211,503
Georgia	1,301,111	74,510	102,856	111,627	88,793	266,159
Florida	1,090,051	57,233	74,033	94,500	77,701	208,967
Ohio	1,049,547	39,131	127,369	139,164	114,098	280,598
Indiana	1,083,235	53,046	123,274	144,264	125,906	302,226
Illinois	1,434,348	43,671	104,526	297,089	118,134	266,331
Michigan	590,921	22,522	76,919	82,849	64,708	164,149
Wisconsin	393,763	13,535	54,331	62,688	56,808	124,674
Minnesota	225,106	10,532	45,453	49,405	24,099	80,084
Iowa	426,928	28,806	64,185	74,081	24,111	117,102
Missouri	753,095	41,884	79,271	150,259	48,760	169,915
North Dakota	31,148	1,356	9,515	9,790	1,560	12,431
South Dakota	11,294	906	2,073	2,352	150	3,129
Nebraska	94,436	16,916	14,124	15,042	458	31,498
Kansas	207,690	21,636	38,650	46,020	2,946	63,232
Kentucky	630,119	29,800	72,406	84,362	49,332	151,538
Tennessee	602,860	40,345	64,553	69,882	47,973	152,871
Alabama	1,342,609	78,753	120,521	131,703	75,064	274,338
Mississippi	825,628	101,361	60,656	67,191	41,838	203,855
Arkansas	358,741	38,578	33,214	35,636	29,698	101,490
Louisiana	330,336	42,842	28,670	31,720	19,058	90,570
Oklahoma	172,655	7,712	20,860	33,816	5,757	34,329
Texas	615,364	50,789	82,974	94,842	20,439	154,202
Montana	23,243	2,262	5,967	6,428	51	8,280
Idaho	73,232	6,937	12,517	13,204	200	19,654
Wyoming	6,756	228	2,162	2,244	19	2,409

TABLE 4-9—Continued

State	Fertilizer	Nitrogen	P ₂ O ₅		K ₂ O	Total available nutrients
			Available	Total		
Colorado	47,531	6,354	10,359	10,625	1,237	17,950
New Mexico	19,080	2,085	4,951	5,063	49	7,085
Arizona	116,507	25,030	11,604	11,915	572	37,206
Utah	30,633	4,250	3,769	3,951	235	8,254
Nevada	5,712	194	593	655	27	814
Washington	91,648	15,815	9,215	10,318	3,764	28,794
Oregon	120,308	17,250	11,295	12,173	2,648	31,193
California	1,627,101	152,742	67,030	70,174	18,274	238,046
Continental U.S.	22,052,197	1,366,401	2,179,940	2,655,759	1,545,398	5,091,739
Territories ^d	380,221	58,379	19,436	22,311	36,069	113,884
Total: 1951-52	22,432,418	1,424,780	2,199,376	2,678,070	1,581,467	5,205,623
1950-51	20,991,394	1,236,977	2,109,900	2,536,988	1,379,813	4,726,690
1949-50	18,343,300	1,005,452	1,949,768	2,290,081	1,103,062	4,058,282

^a Scholl and Wallace⁷¹.

^b Includes as available P₂O₅, 2% of the colloidal phosphate and 3% of the phosphate rock marketed for direct application.

^c Includes as total P₂O₅, 22% of the colloidal phosphate and 32% of the phosphate rock marketed for direct application.

^d Alaska, Hawaii and Puerto Rico.

The business is seasonal, except in the extreme southern parts of the country. About half of the total annual tonnage is shipped in the months of March and April, and about 70 per cent in the first half of the year.

Consumption. The United States consumption of fertilizers and their primary nutrient (N, P₂O₅ and K₂O) contents are given in Table 4-7. The average composition changed only slightly in the 70 years from 1850 to 1920, but the nitrogen and potash contents have increased steadily since then. If present trends continue, the average fertilizer used in the United States will approximate a 10-10-10 grade by 1960.

Consumption by states is presented in Tables 4-8 and 4-9. The states from Maine to Florida used 79.7 per cent of the United States total in 1900, but only 42.2 per cent in 1950. In the same period the Central States increased their consumption from 19.9 to 49.4 and the Western States from 0.4 to 8.4 per cent of the United States total. In 1950, Alaska used 1,000, Hawaii 120,001, and Puerto Rico 322,775 tons, respectively.

The tonnages of the different materials used as fertilizers are estimated in Table 4-10.

Properties. An understanding of certain properties of fertilizers is important for their efficient handling and use. Table 4-11 gives some pertinent data.

TABLE 4-10. ESTIMATED QUANTITIES OF VARIOUS FERTILIZER MATERIALS APPLIED TO THE SOIL IN THE YEARS SHOWN^a
(1000 tons)

Material	1850	1880	1900	1920	1930	1940	1950		
							As separate material	In mixed fertilizer	Total
Chemical nitro- gen									
Ammonia and solutions					67	150	129	720	849
Ammonium nitrate							641	80	721
Ammonium sulfate		4	5	273	611	652	346	900	1,246
Calcium cy- anamide				18	94	80	80	16	96
Sodium nitrate	1	10	37	298	586	760	685	45	730
Other ^b					66	82	173	49	222
Organics									
Castor pomace		2	5	23	40	65	18	64	82
Cottonseed meal		35	434	447	205	115	30	30	60
Fish scrap	10	49	64	110	74	34	2	5	7
Guano and manures	18	80	14	57	145	32	174	15	189
Sewage sludge					40	104	101	63	164
Tankage, animal		20	185	209	68	60	2	8	10
Tankage, garbage			80	139	74	20		10	10
Tankage, process				20	129	93	3	101	104
Other organ- ics ^c		17	48	53	42	43	6	54	60
Phosphates									
Ammonium phosphates				20	48	67	172	80	252
Base goods, wet-mixed			100	377	167	136		65	65
Basic slag			5	10	24	55	362		362
Bone meal	5	82	104	170	85	41	14	10	24
Phosphate rock			9	85	86	156	886	17	903
Superphos- phate, nor- mal	1	357	458	3,020	3,751	3,438	1,865	6,450	8,315

TABLE 4-10—Continued

Material	1850	1880	1900	1920	1930	1940	1950		
							As separate material	In mixed fertilizer	Total
Superphosphate, concentrated		1	1	18	92	339	280	358	638
Other phosphates ^d	10	16	3	20	18	14	40	32	72
Potash									
Kainit		12	171	414	124	30			
Manure salts			48	347	400	52	15	25	40
Chloride		12	65	135	335	624	149	1,675	1,824
Nitrates, ^e	1	1	1	18	14	56	18	2	20
Sulfates ^f		1	22	20	94	69	20	253	273
Tobacco stems		24	45	70	79	95	38	95	133
Other potash ^g	6	22	139	120	18	20	19	22	41
Miscellaneous									
Nitrophoska, etc.				5	13	2			
Gypsum ^h					58	90	418	135	553
Limestone and dolomite ⁱ			14	46	79	331		670	670
Secondary and trace element materials ^j					2	44	40	100	140
Organic fillers ^k		5	20	63	54	80		234	234
Other fillers ^l	1	6	112	631	720	628		650	650
Total	53	753	2,730	7,296	8,425	8,656	6,726	13,033	19,759

^a Includes territories and government distribution.^{40, 42}

^b Calcium nitrate, Leunasalpeter, "Cal-Nitro," urea, etc.

^c Dried blood, linseed meal, tung meal, and many others.

^d Phosphoguanos, precipitated bone, Hi-grade Residue and phosphoric acid.

^e Potassium nitrate and nitrate of soda-potash.

^f Potassium sulfate and sulfate of potash-magnesia.

^g Wood ashes, cotton hull ashes, carbonate, cement flue dust, carnallite, hartsalz, etc.

^h Although gypsum was not included in fertilizer statistics before 1930, it is known that from 120,000 to 160,000 tons were applied annually to the soil between 1840 and 1890. The trend after 1890 was generally downward to a minimum of 46,000 in 1934.

ⁱ Only the amounts used in making mixed fertilizers. Total quantities applied to the soil are given in Table 4-4.

^j Sulfur, sulfur dioxide, magnesia, magnesium sulfate, borax, copper sulfate, manganese sulfate, iron sulfate, zinc sulfate and others.

^k Peat, peanut hulls, furfural waste, oat hulls, compost, and similar material.

^l Sand, and other inert materials.

TABLE 4-11. SOME PROPERTIES OF CHEMICALS COMMONLY USED AS FERTILIZERS

Name	Chemical formula	Mol. wt.	Sp. gr H ₂ O = 1	Solubility in 100 parts of H ₂ O at 32°F, pts	Hygro- scopic point at 86°F ^a	Acidity or basicity equivalent of 100 lb ^b lb CaCO ₃	Salt index ^c
Ammonia	NH ₃	17.03	0.62	90		-148	47
Ammonium nitrate	NH ₄ NO ₃	80.05	1.73	118	59	-59	105
Ammonium phosphate							
mono	NH ₄ H ₂ PO ₄	115.08	1.80	171	92	-65	30
di	(NH ₄) ₂ HPO ₄	132.11	1.62	25	83	-113	34
Ammonium sulfate	(NH ₄) ₂ SO ₄	132.14	1.77	71	79	-110	69
Borax	Na ₂ B ₄ O ₇ ·10H ₂ O	381.43	1.69	3		+55	
Calcium car- bonate	CaCO ₃	100.07	2.70	0.006	100	+100	5
Calcium cy- anamide	CaCN ₂	80.11				+63	31
Calcium metaphos- phate	Ca(PO ₃) ₂	198.12		.001	100	0	0
Calcium nitrate	Ca(NO ₃) ₂ ·4H ₂ O	236.16	1.9	134	47	+16	53
Calcium phos- phate							
mono	CaH ₄ (PO ₄) ₂ ·H ₂ O	252.17	2.22		94	0	15 ^d
di	CaHPO ₄ ·2H ₂ O	173.14	2.31	0.02	100	0	
Calcium sul- fate	CaSO ₄ ·2H ₂ O	172.17	2.32	.24	100	0	8
Copper sul- fate	CuSO ₄ ·5H ₂ O	249.69	2.28	32			
Magnesia	MgO	40.32	3.43	0.0006	100	+230	2
Manganese sulfate	MnSO ₄ ·4H ₂ O	223.06	2.11	105			
Phosphoric acid	H ₃ PO ₄	98.05	1.88	d			
Potassium chloride	KCl	74.55	1.98	28	84	0	114 ^e
Potassium nitrate	KNO ₃	101.10	2.11	13	90	+26	74
Potassium sulfate	K ₂ SO ₄	174.26	2.66	8	96	0	46
Sodium nitrate	NaNO ₃	85.01	2.26	73	72	+29	100
Urea	CO(NH ₂) ₂	60.06	1.3	d	72	-84	75
Zinc sulfate	ZnSO ₄ ·6H ₂ O	269.54	2.07	d			

^a The relative humidity of the atmosphere, at or above which it adsorbs moisture rapidly and with which at equilibrium it becomes a solution. 100 indicates it is non-hygroscopic.

TABLE 4-11—*Continued*

^b A minus sign indicates that the material is physiologically acid and a plus sign that it is basic. The ammoniating solutions all have a physiological acidity equivalent to 36 lb CaCO_3 per unit of nitrogen content. To convert this into the equivalent of 100 lb of the product multiply 36 by the number of times 20 goes into the percentage content of nitrogen. For example, if the solution contains 40.6% nitrogen; $40.6/20 \times 36 = 73.1$ lb of CaCO_3 per 100 of solution. Values for some other fertilizers follow: Dried blood, -23; process tankage -16; tobacco stems +25; bone meals +20 to +25, and superphosphate 0. Other natural organics are approximately neutral.

^c The relative effects of the substances as compared with sodium nitrate. The salt index of N-P-K mixed fertilizers varies from 20 to 90.

^d The salt indices of normal and triple superphosphate are 8 and 10, respectively.

^e 109 and 116 for 50 and 60% KCl, respectively.

Hygroscopicity is the force that causes certain salts to adsorb water from air whenever the relative humidity exceeds the hygroscopic point of the salt. The hygroscopic point is the combination of relative humidity and temperature of the atmosphere where the tension of the water vapor equals the adsorptive force of the salt for water. A damp salt in air with a lower relative humidity dries out, but attracts moisture from air with a higher humidity to become a saturated solution, if exposed long enough.

The hygroscopicity of most salts changes little with normal atmospheric differences in temperature, but ammonium nitrate, calcium nitrate and urea adsorb water at much lower humidities in summer than in winter. Ammonium nitrate, for instance has the following hygroscopic points: 104°F, 52.5; 86°, 59.4; 77°, 62.7; 68°, 66.9; 59°, 69.8; and 50°, 75.3 per cent relative humidity.

Mixtures of two salts usually take up moisture from atmospheres of lower relative humidity than either would alone. Potash salts and phosphates are relatively nonhygroscopic, and mixing them lowers the hygroscopic point only slightly. Mixtures of calcium nitrate, however, with most other salts are too hygroscopic for practical use as fertilizers. Either urea or ammonium nitrate alone can be mixed with superphosphate and potash salts without an undue increase in hygroscopicity, but not with each other. The critical relative humidity at 86°F for this pair is only 18 per cent⁴.

Hygroscopic fertilizers tend to cake, if exposed to the air. When the humidity is high they adsorb a film of moisture, only to lose it again when the humidity drops. The film dissolves salt, which crystallizes out when the water evaporates. Even without change in moisture content, changes in temperature cause salt to dissolve or recrystallize. Such crystallization tends to knit the particles into a solid mass.

Drillability may be defined as the rate of flow of a unit mass in unit time through an orifice when subject to a standard pressure. As the rate of flow decreases the uniformity of distribution possible also decreases. Dry granu-

lar fertilizers flow freely and uniformly, but powders, damp materials, and elongated crystals do not. Ordinary farm distributors cannot dispense uniformly a fertilizer that has poor drillability, and uneven distribution along the row results in reduced crop yields⁵⁰. Thus good drillability is important to the farmer.

A fertilizer of good drillability at the factory may deteriorate before the farmer can apply it to the soil, because of adsorption of moisture by hygroscopic salts. It should, therefore, be protected as much as practical from exposure to damp air. Drillability of a fertilizer often changes while being applied to the soil and this is apt to change the delivery rate, even though the setting of the mechanism of the distributor remains the same⁴⁹.

Although the accurate measurement of drillability is complicated, the angle of repose of a fertilizer is easy to measure and gives a good approximation. The angle of repose is the slope with the horizontal made when the fertilizer is gently poured as in Figure 4-1. It is measured with a protractor level as shown in Figure 4-2. With an angle of 35° drillability is excellent, with 40° it is good, 45° fair, and 50° or higher it is generally unsatisfactory³⁹. In other words when the angle is above 50° the fertilizer either will not flow at all or only very unevenly.

Apparent Specific Gravity. The apparent specific gravity of a fertilizer is its weight divided by the weight of the same volume of pure water at 40°F . All pure substances have a fixed specific gravity (Table 4-11) at any given temperature, but the apparent specific gravity changes considerably with the size and shape of the particles⁵³.

The farmer wants to distribute his fertilizer at a given rate in pounds per acre, but fertilizer distributors dispense by volume and apparent specific gravities vary from about 0.49 for fish scrap to around 1.40 for potassium



Figure 4-1. Proper position of pouring vessel in relation to apex of cone.

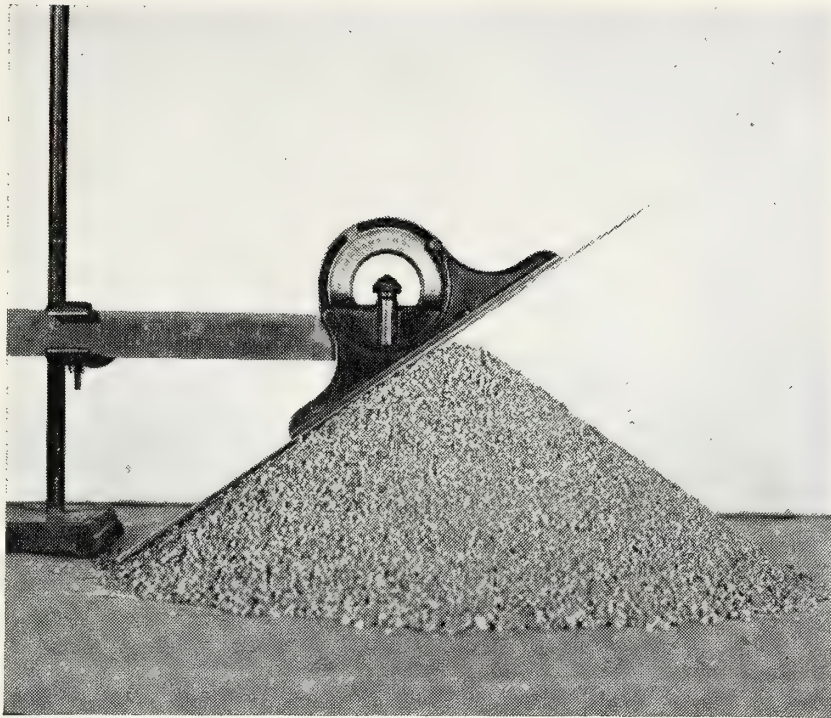


Figure 4-2. Manner of making angle of repose measurements with protractor level.

sulfate. The average values for 37 samples of superphosphate and 256 of mixed fertilizers are 0.91 ± 0.02 and 0.97 ± 0.01 , respectively. The average for sodium nitrate is 1.25.

Salt Index. When applied at excessive rates, or during droughts, certain fertilizer salts cause plants to wilt or die. Superphosphate and natural organics do not, as a rule. Burning is measured by the salt index (Table 4-11) and is due to the effect the salt has in increasing the osmotic pressure of the soil solution⁶².

Physiological Acidity. Some fertilizers change the pH of the soil and these effects are not always what would be expected from the chemical properties. For instance, ammonium sulfate is chemically neutral, but physiologically very acid, and some other fertilizers are just the reverse. Table 4-11 gives the effects of various fertilizers in terms of equivalent amounts of calcium carbonate (see also Pierre⁶⁰).

Nitrogen

Before 1900 more than 90 per cent of all fertilizer nitrogen was in the form of natural organics, but since 1950 has totaled less than 4 per cent. Chemicals in 1950 supplied 1,091,000 out of a total of 1,126,000 tons. Sodium nitrate from Chile and by-product ammonium sulfate together furnished practically all the chemical nitrogen until 1909, when calcium cyanamide was introduced. Now many different materials are used as nitrogenous fertilizers, but the bulk of the tonnage is derived from synthetic ammonia. Of the 1,500,000 tons of nitrogen consumed in 1952, 45 per cent was in the form of commercial mixed fertilizers and 55 per cent as separate materials.

TABLE 4-12. AVERAGE WHOLESALE PRICES PER UNIT (20 POUNDS) OF NITROGEN AT PRODUCING POINTS OR PORTS IN BULK CAR LOTS^a

Calendar year	Ammonium sulfate	Anhydrous ammonia	Calcium cyanamide	Sodium nitrate	Solutions ^b	Natural organics
1880	\$4.01			\$4.13		\$3.42
1890	3.18			2.33		2.46
1900	2.79			2.37		2.57
1910	2.64		\$3.43	2.76		3.63
1920	4.08		3.40	4.44		8.71
1930	1.79	\$1.40	1.65	2.49		4.50
1940	1.37	1.09	1.20	1.68	\$1.22	3.55
1950	1.95	0.91	2.26	3.00	1.20	8.66
1951	1.97	.97	2.90	3.16	1.20	9.14
1952	2.06	.97	3.11	3.34	1.20	9.23

^a Largely computed from quotations published weekly in the *Oil, Paint and Drug Reporter*. A few were obtained directly from the producers.

^b Averages of the quotations for "Nitrogen solutions" and "UAL."

^c 1880-1930, computed from the quotations for fish scrap, animal tankage, dried blood and cottonseed meal. 1940-52, castor pomace, process tankage, fish scrap, cottonseed meal and animal tankage. Allowances for P₂O₅ and K₂O were deducted from the ton prices and the remainder was divided by the average N content.

The prices in Table 4-12 help to explain the changes in usage. The nitrogen contents of various fertilizers are indicated in Table 4-13.

Ammonia. Both aqua ammonia from coke ovens and synthetic anhydrous ammonia are used as fertilizers. One-fifth of the nitrogen applied to the soil in the form of separate materials in 1952 was free ammonia. See also ammoniated superphosphate, p. 121.

Anhydrous ammonia (NH₃) was first applied commercially to irrigation water in California in 1935, and to the soil in Mississippi in 1946. This is the cheapest form of fertilizer nitrogen at many points, but only a farmer operating a larger acreage can afford the equipment required to store and apply it. Many companies apply it for farmers on a customs basis. For shipment the gas is compressed into a liquid, which has a guage pressure of 40 psi at 25°F and 197 psi at 100°. The liquid weighs 5.15 pounds per gallon. Care is necessary to handle anhydrous ammonia safely.

Aqua ammonia or "B liquor" is a solution of ammonium hydroxide, NH₄OH, in water. It contains from 19 to 24, with an average of 20.67 per cent nitrogen. Such solutions do not exert pressures at ordinary temperatures, but a 25 per cent ammonia liquor (21 per cent N) has a gauge pressure of 1 at 100° and 9 psi at 120°F. The weight of aqua ammonia is about 7.56 pounds per gallon. For manufacturing technology see Jacob^{31, II and III}.

Ammonium Nitrate. This material (NH₄NO₃) is very hygroscopic (Table 4-11). At 92°F it changes its crystal form, with a 3.8 per cent change in volume. These properties discouraged its use as a fertilizer until 1942, although it was used previously in mixtures with limestone ("Cal-Nitro")

TABLE 4-13. AVERAGE PERCENTAGE OF PRIMARY NUTRIENTS AND MOISTURE IN COMMERCIAL FERTILIZERS^a

Fertilizer	No. of samples ^b	N		P ₂ O ₅		K ₂ O	Moisture
		H ₂ O-Sol.	Total	Available	Total		
Ammonia, anhydrous	183	81.5	81.5				0.05
Ammoniated super-phosphate	45	3.89	4.00	17.30	18.82	0.24	9.10 ^c
Ammonium nitrate	1,753	33.43	33.43				
Ammonium nitrate-limestone	206	20.70	20.70				2.13
Ammonium phosphate (11-48)	262	10.81	11.27	48.48	49.32	.22	1.64
Ammonium phosphate-nitrate (28-14)	4	27.43	27.43	15.13	15.23		0.53
Ammonium phosphate-sulfate (16-20)	668	16.20	16.40	20.61	21.06	.18	.63
Ammonium sulfate							
By-product	6,586	20.74	20.74		0.07	.47	.38
Synthetic	109	21.09	21.09				.16
Ammonium sulfate-nitrate	20	25.88	25.88				.61
Basic slag							
Bessemer	533			15.59 ^d	17.64		.35
Open-hearth	297			10.19 ^d	11.88		.10
Bone meal							
Raw	893	0.73	3.87	12.46	22.46	.20	6.58
Steamed	1,566	.49	2.24	13.93	27.42	.11	5.60
Calcium cyanamide	2,050	21.08	21.77				0.62
Calcium metaphosphate	11				61.79		.17
Calcium nitrate	168	15.43	15.43				8.23 ^e
Calcium nitrate-urea	73	33.66	33.78				2.96
Castor pomace	1,498	0.53	5.20	1.67	1.81	1.09	9.55
Cement flue dust	245				0.65	5.57	1.52
Cocoa shells	49	.68	2.45	0.72	1.01	2.68	5.82
Cotton hull ashes	425				5.31	26.69	7.79
Cottonseed meal	40,466	.68	6.43	2.51	2.59	1.74	7.92
Crab scrap							
Blue	50	.99	4.63	3.59	3.77	0.50	8.31
Horseshoe, or king	152		9.57	1.32	1.37	.38	8.50
Dried blood	1,076	1.10	12.91	.59	1.50	.57	9.32
Dried manure							
Cattle	446	0.42	2.03	1.34	1.47	2.22	7.19
Poultry	277	2.45	4.47	2.62	2.73	1.35	9.22
Sheep	2,195	0.53	1.87	1.34	1.41	2.91	11.40
Fish scrap, dried	3,090	2.22	9.36	4.99	7.12	0.79	4.52
Fused rock phosphate	15			23.37	27.74		0.10
Guano							
Bat	366	2.80	5.73	6.43	8.63	2.00	16.68
Peruvian	136	9.36	12.49	10.30	11.23	2.41	15.11

TABLE 4-13—Continued

Fertilizer	No. of samples ^b	N		P ₂ O ₅		K ₂ O	Moisture
		H ₂ O-Sol.	Total	Available	Total		
Gypsum	218		0.02		0.04	0.49	3.71
Hempseed meal	76		4.92	2.21	2.78	1.17	10.79
Hoof and horn meal (steamed)	82	1.25	13.83		1.13		9.90
Kainit	3,227					16.42	1.99
Kieserite, calcined	45					0.12	1.26
Linseed meal	637	1.84	5.60	1.80	1.80	1.31	8.94
Manure salts							
20% imported	394	0.20	0.20			21.21	1.12
25% domestic	182					25.29	0.60
Mixed fertilizers							
N-K	1,266	9.83	10.28			10.30	1.28
N-P	1,674	8.07	8.47	17.16	18.01		4.81
N-P-K	10,213	3.70	4.02	10.36	11.19	7.06	4.07
P-K	3,131	0.03	0.07	13.89	14.64	12.21	4.62
“Nitrophoska”	213	14.16	14.26	21.96	23.01	18.35	.50
Phosphate rock							
Florida land pebble	121		0.01	6.53 ^d	31.99	0.20	1.03
Florida hard rock	24		.01	6.75 ^d	34.17	.13	1.05
Florida waste pond ^e	88		.06	5.70 ^d	19.62	.57	4.34
Idaho	28		.10	6.72 ^d	32.04	.36	0.74
Montana	22		.01	5.21 ^d	32.80	.30	.70
Tennessee brown	65		.01	5.90 ^d	32.70	.48	2.05
Wyoming	17		.11	4.15 ^d	30.67	.35	0.68
Phosphoguanos	70		.25		27.02	.59	7.26
Phosphoric acid, wet process	95			52.33	52.33	.04	27.34
Potassium chloride:							
50%, imported	3,687					50.75	1.45
60%, domestic	1,076					60.88	0.26
Potassium-magnesium sulfate	55					21.85	0.30
Potassium nitrate	157	12.96	12.96			44.51	2.01
Potassium sulfate	1,444					49.40	0.52
Precipitated bone phosphate	323			38.87	40.36	0.15	0.22
Rapeseed meal	110	1.23	5.42	1.75	2.08	1.28	9.89
Seasalt	276	0.001	0.001	0.01	0.01	1.33	
Sesameseed meal	45	1.30	6.27	1.78	2.33	1.29	8.09
Sewage sludge							
Dried digested	215	0.34	1.87	1.22	1.40	0.86	16.65
Dried activated	523	.68	5.81	2.42	2.92	.58	5.07
Shrimp scrap	20		7.06	3.38	4.42	.73	11.64
Sodium-potassium nitrate	604	14.83	14.83			14.62	1.58

TABLE 4-13—*Continued*

Fertilizer	No. of samples ^b	N		P ₂ O ₅		K ₂ O	Moisture
		H ₂ O-Sol.	Total	Available	Total		
Sodium nitrate							
Chilean (Champion)	719	16.13	16.13		0.08	0.18	0.43
Domestic (synthetic)	516	16.21	16.21			.05	.34
Soot	24	2.04	2.84		0.70	.63	7.99
Soybean meal	290	3.64	6.76	1.01	1.61	2.37	8.88
Starfish meal	23		4.96		0.79	0.81	10.74
Superphosphate							
Normal	13,219		0.10	19.68 ^f	20.46	.24	5.82 ^c
Triple	2,639		.26	45.41 ^g	46.89	.35	3.30 ^c
Tankage							
Animal	6,062	2.34	7.17	6.26	10.57	.40	6.76
Garbage	245	0.61	2.77	2.02	3.06	1.14	6.42
Process	193	1.69	8.10	0.70	0.98	0.10	6.49
Whale	75	2.78	10.43	3.29	4.69	.33	5.74
“Techmangam” (all grades)	16	2.16	2.16	0.13	0.13		0.21
Tobacco stems	359	0.77	1.99	.65	.70	6.02	12.76
Tungnut meal	16		4.34		1.73	1.31	5.65
“Uramon”	218	42.10	42.34	.03	0.04	0.10	1.46
Wood ashes	3,053			.78	1.58	5.47	11.78
Wool waste	266	0.31	3.66	.34	0.34	1.72	9.27

^a All available data for materials that have not changed with time. Determinations for superphosphate, most of the chemicals and the mixed fertilizers were collected from publications dated 1940 to 1950. Blank spaces indicate that no data are available. In most cases this means very little or none of this nutrient is present.

^b The number for N, available P₂O₅ or K₂O whichever is the principal nutrient. The number of determinations of water-soluble N, total P₂O₅ and moisture were usually considerably less, but numerous enough to be representative.

^c By the method of drying at 110°C⁹, which with this material gives high results because some water of crystallization is also driven off.

^d Soluble in 2% citric acid solution.

^e Including colloidal phosphate.

^f Including the P₂O₅ content of 1.21% free H₃PO₄.

^g Including the P₂O₅ content of 2.79% free H₃PO₄.

and ammonium sulfate (“Leunasalpeter”), and in solution (“Nitrogen Solution”)⁷⁰. It is one of the most economical solid nitrogenous fertilizers, however, and therefore ways were finally found to make it acceptable to farmers⁶⁴.

It is usually prepared by neutralizing about 60 per cent nitric acid with ammonia and evaporating the solution almost to dryness. It is then sprayed into a current of cool dry air. The resulting pellets are coated with about 0.7 per cent of a water-repellent mixture of petrolatum, paraffin, and/or rosin,

and finally with about 5 per cent of clay. This product can be stored satisfactorily in moisture-resistant bags.

Ammonium nitrate is explosive, but only under conditions that are not encountered in its ordinary use as a fertilizer. Its decomposition is endothermic. It should not be dynamited, nor stored in contact with flammable materials, nor mixed with organics and superphosphate, unless the free acid of the latter is neutralized. In case of fire the best procedure is to apply plenty of water.

Ammonium Nitrate-limestone Mixtures. "Cal-Nitro" and "Nitro-chalk" have been imported, off and on, since 1930. "Cal-Nitro" and "ANL" have also been produced at Hopewell, Va., since 1943, by mixing one-third dolomitic limestone with two-thirds ammonium nitrate and granulating. These materials are nonexplosive.

Ammonium Sulfate. Before 1900 the supply of this fertilizer, $(\text{NH}_4)_2\text{SO}_4$, was a by-product of the gas light industry. In 1950, 831,016 tons were a by-product of coke ovens, 1,050,226 tons were made from synthetic ammonia and very little came from gas works. The average nitrogen content of this fertilizer increased from 20.23 per cent in 1870 to 20.85 in 1953. The mean moisture content simultaneously decreased from 3.55 to 0.10 per cent. The by-product material is generally gray in color and smells of pyridine (mean content 0.06 per cent), whereas synthetic sulfate is white and odorless.

Calcium Cyanamide. Lime and coke heated together at 2200°C in nitrogen form calcium cyanamide. Practically the entire supply for the United States is imported from Niagara Falls, Ont. Pure CaCN_2 is white and contains 34.98 per cent of nitrogen but "Cyanamid" is only 60 per cent pure. It contains 15 to 20 per cent of calcium hydroxide, 2 to 6 per cent of calcium carbonate, small amounts of urea and other nitrogenous compounds, and 11 to 13 per cent of graphite, which colors it black.

Granular "Cyanamid" is used for direct application and powder containing 5 per cent of mineral oil is used in mixed fertilizers. The oil is added to prevent dustiness. Calcium cyanamide sometimes contains quicklime, which can cause injury, so if it gets on the skin, it should be washed off promptly. In pure water cyanamide polymerizes to dicyandiamide, $(\text{CN})_2(\text{NH}_2)_2$, but in most soil solutions it hydrolyzes to urea. Landis³⁵ discusses its reactions in fertilizer mixtures. In 1950, 45 samples of granular "Cyanamid" averaged 20.90 ± 0.11 per cent of nitrogen.

Calcium Nitrate. First produced in Norway from arc-process nitric acid, calcium nitrate, $\text{Ca}(\text{NO}_3)_2$, is now manufactured from synthetic ammonia. It is also a by-product of the manufacture of nitric superphosphate in Europe. About half of the 44,329 tons imported in 1950 was used in California. The material now available is mostly the double salt $5\text{Ca}(\text{NO}_3)_2 \cdot \text{NH}_4\text{NO}_3 \cdot 10\text{H}_2\text{O}$, which is less hygroscopic than the normal salt.

Natural Organics. Many different by-products of animal or vegetable origin have been used as fertilizers, conditioners (only in mixed fertilizers), or rough ammoniates. The compositions of the more important ones are shown in Tables 4-13, 4-14 and 4-15.

Fertilizer organics, chiefly Peruvian guano, fish scrap, and bone meal, supplied nearly all of the commercial nitrogen prior to 1870. Then oil-seed meals, animal tankage and garbage tankage became important. Now the bulk of the tonnage of nitrogenous organics consists of materials unfit for feed, such as sewage sludge, castor pomace, and process tankage.

The nitrogen of some organics is much more available as a plant nutrient than that of others. This difference is distinguished by use of the alkaline-, or neutral-potassium permanganate methods of analysis⁹. Dried blood, oil-seed meals, fish scrap and animal tankage contain nitrogen in forms that rapidly become available to plants in the soil, but untreated rough ammoniates do not. The nitrogen of peat, garbage tankage and process tankage is intermediate in value.

Rough ammoniates are organics whose nitrogen is in the form of keratin or other compound not easily decomposed and unavailable to plants. They include feathers, hair, hoofs, horns, leather scrap, silk and woolen rags and similar materials. Such materials contain from 7 to 15 per cent of nitrogen, most of which can be rendered available by treatment under pressure with steam, or with sulfuric acid.

Feather meal, hoof and horn meal, and process tankage are made by steaming appropriate materials under a pressure of 30 to 100 psi. Any of the rough ammoniates may be used to make process tankage, but the largest tonnage consists of leather scrap. The use of chrome-tanned leather may introduce harmful amounts of chromium into the product (see Footnote f, Table 4-15). See also wet-mixed base, p. 127

For further details on the following refer to the literature indicated: castor pomace²⁸, cocoa shells⁷⁸, cottonseed meal²¹, fish scrap⁷⁴, sewage sludge^{22, 59, 68}, process tankage^{27, 67}, bat guano⁶, and Peruvian guano¹⁹.

Sodium Nitrate. Chilean saltpeter has been imported for more than a century, and since 1929 it has been produced synthetically in the United States. During World War II it was also produced as a by-product of munitions manufacture. The crude ore mined in the desert of Northern Chile is refined by two different processes. The old or Shanks process produces large crystals, and the Guggenheim process, introduced in 1927, makes round pellets²⁴. Typical Shanks process material contained 92 per cent of sodium nitrate (NaNO_3), 2.5 per cent of potassium nitrate, 2.7 per cent of moisture and small amounts of numerous other substances. It averaged 15.55 per cent of nitrogen. The Guggenheim and synthetic salts both are from 98 to 99 per cent pure. The mean nitrogen content of 2695 samples of all types analyzed in control laboratories since 1940 is 16.12 ± 0.02 per cent.

TABLE 4-14. AVERAGE PERCENTAGE OF SECONDARY AND TRACE NUTRIENTS IN COMMERCIAL FERTILIZERS^a

Fertilizer	CaO	MgO	SO ₃ ^b	CuO	MnO	ZnO	B ₂ O ₃
Ammoniated super-phosphate	24.02	0.63	28.30		0.004		0.051
Ammonium nitrate				0.004		0.015	
Ammonium nitrate-limestone	10.18	7.34					
Ammonium phosphate (11-48)	1.51	0.46	5.59	.02	.04	.042	.06
Ammonium phosphate-sulfate	0.40	.17	38.49	.03	.30	.023	.09
Ammonium sulfate	.37		59.35	.032	.001	.015	
Ammonium sulfate-nitrate			37.79	.0036	.0068	.003	
Basic slag							
Bessemer	46.46	6.86	7.45	.0014	4.44	.0007	.0067
Open-hearth	40.54	5.69	0.80	.0020	2.86	.0025	.0054
Bone meal							
Raw	30.68	0.74	0.38	.0005	0.0014	.018	
Steamed	35.26	.37	0.32				
Calcium cyanamide	53.88	.10	.82	.02	.05		
Calcium nitrate	27.24	2.49	0.05	.003	.011	.003	
Calcium nitrate urea	13.11			.002		.0029	
Castor pomace	0.58	0.53	0.09	.006	.05	.06	.042
Cement flue dust	43.02	5.24	8.29				
Cocoa shells	1.31	0.57	0.23	.021			.0037
Copper sulfate			32.13	31.09		.68	
Cottonhull ashes	9.60	5.18	2.42	0.051	.071	.082	.02
Cottonseed meal	0.34	0.70	0.75	.0055	.0026	.028	.0046
Crab scrap							
Blue	26.13	1.13	0.73	.0058		.0029	
Horseshoe or king	4.36	0.37	5.17				
Dried blood	0.34	.17	0.42	.0009	.0005	.003	.0032
Dried manure							
Cattle	4.01	1.19	0.29		.043		
Poultry	4.07	1.07	1.93				.003
Sheep	4.58	1.27	1.27				
Epsom salt	3.11	17.41	34.89				
Fish scrap	8.41	0.38	0.43	.0014	.0012	.011	
Fused rock phosphate	40.18						
Guano							
Bat	7.71	.68	1.86				
Peruvian	12.27	1.00	2.75	.01	.025	.003	.015
Gypsum	31.44	0.61	42.05				
Hempseed meal	1.83	.44	0.015		.009	.010	

TABLE 4-14—Continued

Fertilizer	CaO	MgO	SO ₃ ^b	CuO	MnO	ZnO	B ₂ O ₃
Hoof and horn meal	2.65	0.20	3.40				
Kainit	1.49	5.84	18.89	0.001			0.006
Kieserite, calcined	1.52	29.78	64.71				
Linseed meal	0.58	0.81	0.93	.0027	0.0096	0.0026	
Magnesia (sea water)	1.47	93.15	.50				
Manganese sulfate	9.26	3.12	36.18	.06	32.33	.10	.93
Manure salts							
20% imported	1.06	5.92	9.01				.006
25% domestic	0.28	0.25	0.69				.03
Mixed fertilizers:							
N-K	7.23	4.16	4.71	.44	0.61	.06	.036
N-P-K	16.62	2.07	19.31	.03	.08	.04	.03
P-K	19.93	1.67	15.69	.05	.118	.027	
“Nitrophoska”	6.18	0.76	1.47	.006	.188	.008	.008
Phosphate rock							
Florida land pebble	46.29	.27	0.72	.001	.042	.002	.001
Florida hard rock	41.84	.23	.14	.001	.054	.001	.045
Florida waste pond	26.80	.99	.21	.024	.114	.005	.43
Idaho	46.01	.41	1.52	.011	.017	.001	
Montana	47.04	.21	0.38	.011	.035	.025	
Tennessee brown	45.27	.14	.78	.004	.200	.005	.039
Wyoming	46.17	.25	3.00	.010	.004	.0005	
Phosphoguanos	35.50	1.74	1.64				
Phosphoric acid, wet process	0.06	0.30	2.25	.009	.171	.055	
Potash-magnesia, sulfate of	.01	18.57	56.76	.0000	.0012	.0009	.0042
Potassium chloride							
50% imported	.39	0.50	0.89	.0006	Trace	.00005	.0043
60% domestic	.11	.20	.28	.0000	0.0002	.0002	.09
Potassium nitrate	.59	.38	.73				.28
Potassium sulfate	.71	1.16	44.09	.001			.006
Precipitated bone	31.04	0.62	3.36	.005			
Rapeseed meal	0.87	.56	0.57		.0088		.004
Seasalt	1.67	6.17	6.41	.0094	.0026	.0015	.014
Sesameseed meal	3.51	1.29	.09				
Sewage sludge							
Dried digested	2.91	0.90	.35	.358	.41	.45	Trace
Dried activated	1.76	1.15	1.34	.087	.094	.130	0.006
Shrimp scrap	7.68			.0044	.0001	.002	
Soda-potash, nitrate of							.39
Sodium borate (Borax)							37.38

TABLE 4-14—Continued

Fertilizer	CaO	MgO	SO ₃ ^b	CuO	MnO	ZnO	B ₂ O ₃
Sodium nitrate							
Chilean (Champion)	0.16	0.08	0.19	0.004			0.040
Domestic (synthetic)	.10	.06	.17	.000			.000
Soot	2.91	1.18	6.22				
Soybean meal	0.36	0.51	0.53	.0019	0.0029	0.0023	.006
Starfish meal	23.09	2.06	.47	.0056		.0056	.013
Superphosphate							
Normal	28.60	0.26	29.74	.005	.012	.013	.004
Concentrated	19.99	.38	3.40	.015	.019	.005	.036
Tankage							
Animal	13.33	.35	1.23	.010	.0014	.021	.019
Garbage	4.20	.45	1.52	.05			
Process	1.06	.02	2.26	.0001	.008	.009	.088
Whale	8.85	.35		.00		.01	
“Techmangam”	1.52	2.49	50.59	.02	34.86	.45	.02
Tobacco stems	5.02	0.60	0.96	.016	0.041		.064
Tungnut meal	0.64	.86			.0034		
“Uramon”	1.93	1.20	.049	.003	.009	.024	
Wood ashes	32.87	3.41	.92	.16	.97	.25	.48
Wool waste	0.32	0.06					
Zinc sulfate		.10	33.90	.03	.008	34.52	

^a See footnote *a* of Table 4-13. The numbers of samples for the CaO, MgO and SO₃ determinations were large enough to be representative. Those for trace nutrients varied from 1 to 20 and in some cases may not be truly representative.

^b Total sulfur computed to SO₃. In the organics the sulfur is present in the organic matter. All or most of it in the basic slag and calcium cyanamide and part of it in the phosphate rock is in the form of sulfide.

Solutions. Several types of solutions are used as fertilizers and may be classified as ammonium nitrate-water, ammonium nitrate-ammonia-water, urea-ammonia-water, starter solutions, and liquid mixed fertilizers. The last two will be discussed under mixed fertilizers.

Ammonium nitrate-water solution contains 60-80 per cent of salt or 21-28 per cent of nitrogen. It is simply the solution resulting from the neutralization of nitric acid with ammonia. It is an economical fertilizer for direct application.

Ammonium nitrate-ammonia-water-solutions are widely used to ammoniate superphosphate and to a minor extent as a separate fertilizer. Several types are on the market, but the one most widely used is known as A or 2A. Table 4-16 gives the compositions and properties of the principal kinds. Figure 4-3 shows the change in vapor pressure with temperature.

TABLE 4-15. AVERAGE PERCENTAGE OF SOME MISCELLANEOUS CONSTITUENTS OF
COMMERCIAL FERTILIZERS^a

Fertilizer	CO ₂	Cl	F	Na ₂ O	R ₂ O ₃ ^b	SiO ₂ and acid insoluble	Organic matter
Ammonium nitrate-lime- stone	17.02	0.40				2.07	
Basic slag							
Bessemer			0.07		13.63 ^c	7.77	
Open-hearth			.28		22.29 ^d	8.00	
Bone meal							
Raw	1.62	.29	.50	0.46	0.004	1.44	33.48
Steamed	2.21	.18	.12	.40	.15	2.08	25.48
Calcium cyanamide ^a	0.75	.25			1.35	1.38	7.59
Castor pomace		.34			1.21	1.13	83.61
Cement flue dust	13.11	3.03			2.88	16.06	
Cocoa shells		0.06		.38	0.18	3.24	83.67
Cottonhull ashes	20.92	1.88			1.85	15.78	
Cottonseed meal		0.059	.0012	.20	0.047	0.89	84.97
Crab scrap							
Blue	17.40	.82		1.05	.10		40.88
Horseshoe				1.10	.82	3.88	77.12
Dried blood		.51		0.47	.14	2.00	85.16
Dried manure							
Cattle		.56		.15		8.31	69.86
Poultry				.48	.13	17.47	58.61
Sheep		1.12		1.41		15.27	53.95
Fish scrap	2.42	0.44	.02	.52	.08	0.91	70.44
Guano							
Bat	1.15	.62		.46	2.81	2.47	55.14
Peruvian	2.15	1.69	.04	1.09	2.20	7.69	35.85
Gypsum	1.78	0.27		.62	2.28	7.13	0.26
Hempseed meal		.006		.06	0.053	0.92	81.52
Linseed meal		.05		.49	.06	1.24	85.27
Magnesia (seawater)	1.73	.48		.39	.46	1.61	
Manure salts							
20% imported		42.06		19.87	.02	1.56	
25% domestic		54.31		28.33		1.00	
Mixed fertilizers							
N-K	9.82	6.00		8.26	.26	10.21	10.09
N-P-K	3.10	5.72	.67	1.65	1.46	10.95	6.67
P-K	1.65	9.24	.97	2.46	1.97	8.72	0.40
“Nitrophoska”	0.22	15.57	.62	1.82	1.83	0.79	
Phosphate rock							
Florida land pebble	2.91	0.13	3.82	.43	2.63	8.22	2.33
Florida hard rock	2.25	.018	3.36	.18	6.42	7.24	4.93
Florida waste pond	2.08	.009	1.50	.34	16.19	19.56	6.70
Idaho	2.36	.025	3.48	.73	2.28	7.21	3.60
Montana	1.50	.011	3.17	.35	1.93	8.66	3.91
Tennessee brown	1.57	.019	3.44	.34	4.54	7.52	1.83
Wyoming	3.28	.02	3.23	.81	1.94	7.19	5.45

TABLE 4-15—Continued

Fertilizer	CO ₂	Cl	F	Na ₂ O	R ₂ O ^{3b}	SiO ₂ and acid insoluble	Organic matter
Phosphoguano	2.78	.40	0.50	1.25	8.82	3.58	9.58
Potassium chloride							
50% imported		47.66		6.68	0.22	0.64	
60% domestic	0.04	47.02		1.40	.04	.09	
Potassium sulfate	.19	2.07		1.03	.52	.79	
Precipitated bone	.39	0.97	.02	0.22	1.87	1.97	
Rapeseed meal	1.62	.03		.29	0.29	0.24	82.34
Seasalt	0.15	55.29	.0009	41.24	.02	.015	
Sesameseed meal		0.02		0.18	.30	.31	82.52
Sewage sludge:							
Dried digested		.21		1.30	7.29	29.84	38.22
Dried activated		.65		1.07	8.24	12.07	64.40
Shrimp scrap	5.19	2.21		1.56	0.013		69.24
Soda-potash, nitrate of		0.47		24.21			
Sodium nitrate							
Chilean (Champion)		.40		35.94	.10	0.20	
Domestic (synthetic)	0.10	.24		36.24	.00	.07	
Soybean meal		.05		0.15	.05	.04	85.44
Starfish meal	20.06	1.82		.62	.52	1.21	36.93
Superphosphate:							
Normal		0.27	1.64	.09	.97	4.83	
Concentrated			1.56	.97	3.29	4.42	
Tankage:							
Animal		.76		.98	0.09	1.28	64.10
Garbage	0.59	1.27		1.61	.41	10.02	71.20
Process ^f		0.85		0.99	3.79	1.13	82.88
Whale				3.44			78.40
Tobacco stems		1.23		0.52	0.68	1.16	68.96
Tungnut meal						1.03	85.24
"Uramon"	2.82	0.15				1.30	
Wood ashes	23.91	.30		1.81	4.66	12.82	
Wool waste		1.93			0.80	8.73	76.77

^a See footnote *a* of Table 4-13. Many other constituents (PbO, SnO₃, TiO₂, V₂O₃, Br, etc.) have been found in small amounts in certain materials.

^b The sum of Al₂O₃ and Fe₂O₃. In the natural organics, except guanos, it is almost entirely Fe₂O₃.

^c Contains 5.14% FeO in addition.

^d Contains also 6.42% of FeO.

^e Also contains 11.87% graphite.

^f Nine unpublished determinations made by J. S. Rogers, U. S. Bureau of Chemistry, Eastern Regional Lab. vary from 0.53 to 2.56, and average 1.22 per cent Cr₂O₃.

TABLE 4-16. COMPOSITION AND PROPERTIES OF AMMONIATING SOLUTIONS

Type	Free NH ₃ (%)	Solids in solution (%)	Water (%)	Ammonia N (%)	Total N ^a (%)	Sp Gr at 60°F	Salting- out temp. (°F)	Salt index ^b
Ammonium ni- trate								
2	20.0	60.0	20.0	27.0	37.5	1.14	18	
2A or A	21.7	65.0	13.3	29.2	40.6	1.14	23	78.3
3 or B	26.0	55.5	18.5	31.2	40.8	1.08	-13	70.4
4 or C	16.6	66.8	16.6	25.4	37.0	1.18	48	77.8
5	6.0	60.0	34.0	15.6	26.0	1.23		
6 or D	34.0	60.0	6.0	38.5	49.0	1.04	-52	
Urea								
A	36.8	38.4 ^c	24.8	30.4	45.5	.99	5	41.7
B	30.5	31.9 ^c	17.6	25.3	45.5	1.06	34	47.0
C	30.0	31.4 ^c	38.6	24.7	37.0	1.00	6	
D	25.0	42.2 ^c	32.8	20.6	37.0	1.05	34	
37	25.0	42.3 ^d	24.8	20.6	37.1	1.08	34	26.5

^a The difference between the total and ammonia N consists of nitrate N in the ammonium nitrate-ammonia-water solutions, and of organic N in the urea-ammonia-liquors.

- ^b Rader, White and Whittaker⁶².
^c Urea and ammonium carbamate.
^d Urea, ammonium carbamate and hexamethylenamine.

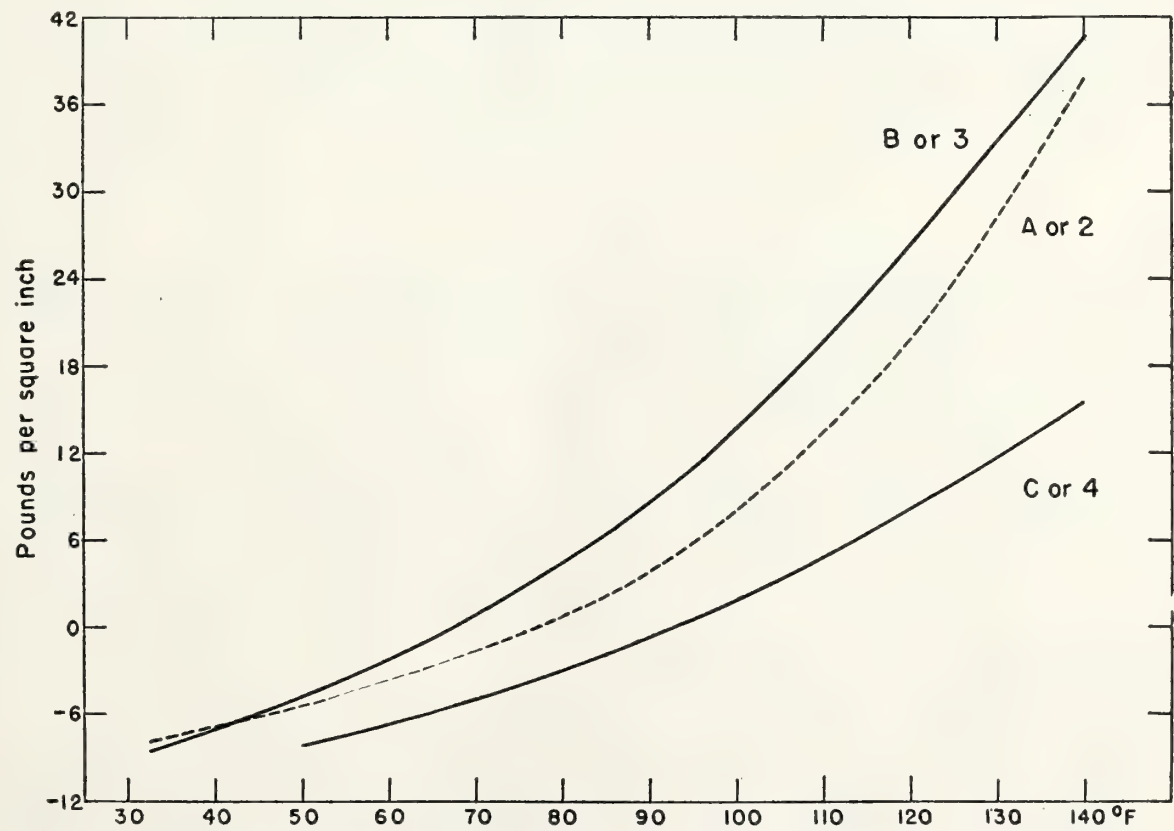


Figure 4-3. Vapor pressures of ammonium nitrate-ammonia water solutions of various temperatures.

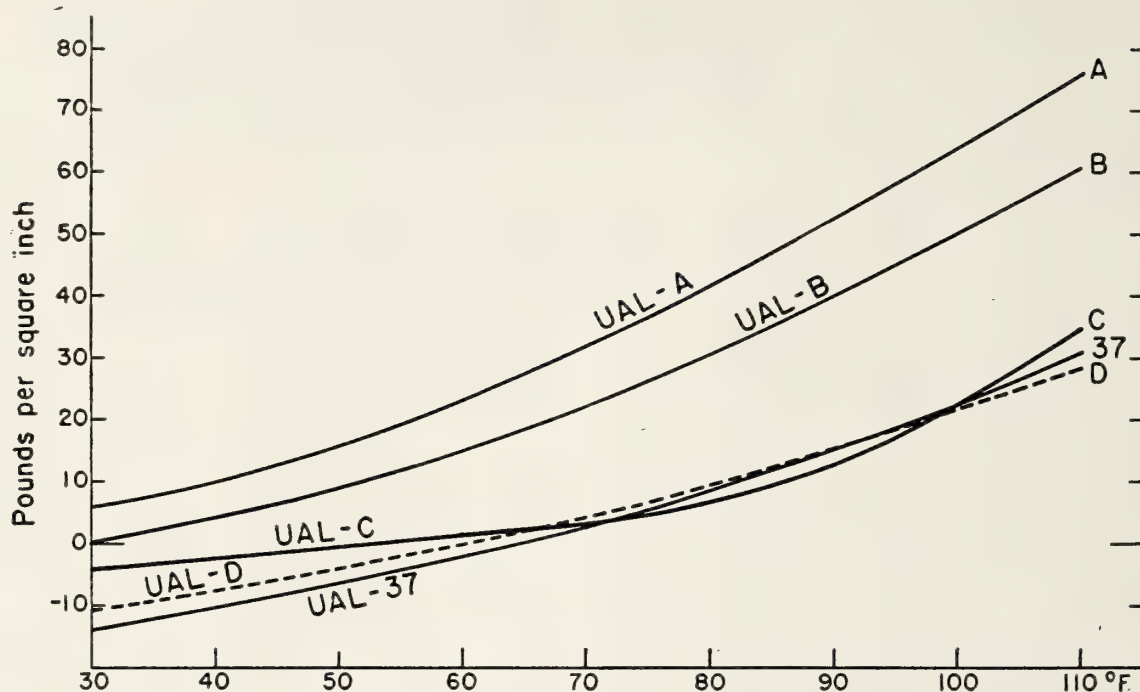


Figure 4-4. Vapor pressure of urea-ammonia liquors of various temperatures.

Urea-ammonia-liquors were introduced in 1932. They contain from 25 to 36.8 per cent of free ammonia and from 31.4 to 51.9 per cent of solids, consisting of urea and ammonium carbamate, $\text{NH}_4 \cdot \text{NH}_2\text{CO}_2$ (Table 4-16). "UAL-37" contains hexamethylenamine, which decomposes to form formaldehyde when the ammonia is neutralized with superphosphate. This in turn reacts with the urea to make water-insoluble nitrogen compounds. The vapor pressure of these solutions at various temperatures is shown in Figure 4-4.

Urea

Nitrogenous compounds broken down in living animals are largely eliminated in the urine as urea $(\text{NH}_2)_2\text{CO}$. Urea is synthesized commercially by compressing a mixture of ammonia and carbon dioxide at elevated temperatures. At atmospheric pressure urea slowly decomposes at the boiling point of water. Insoluble but slowly available fertilizers are made by reacting urea and formaldehyde. These materials are nonhygroscopic and contain 36 to 39 per cent of nitrogen. They are good coating agents and therefore may serve also as conditioners for hygroscopic salts. Urea has been imported since 1920 and manufactured in this country since 1935. 22,575 tons were imported in 1951.

"Nugreen" is urea conditioned with soluble starch and is used in spray solutions to feed plants through the leaves. It contains 44.56 ± 0.12 per cent of nitrogen. "Uramon" is conditioned with insoluble substances, such as cocoashell meal, and contains 42.34 ± 0.05 per cent of nitrogen.

"Ureor" is imported urea in the form of pellets coated with diatomaceous earth. It contains 40.41 ± 0.11 per cent of nitrogen.

Phosphorus

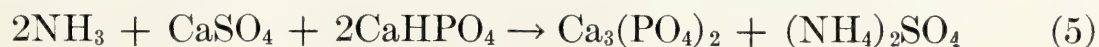
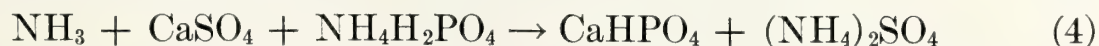
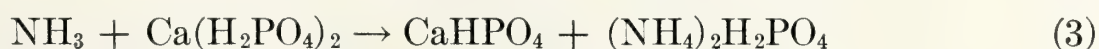
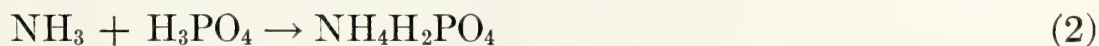
In order to distinguish clearly between real phosphoric acid, H_3PO_4 , and its anhydride, P_2O_5 , the latter is called phosphoric oxide. All phosphorus in natural organics is considered to be available, but the available in superphosphates and mixed fertilizers is the sum of the water- and neutral-ammonium-citrate-soluble phosphorus, and in slags and metaphosphates it is the part soluble in 2-per cent citric acid solution⁹.

Although most natural organics are thought of as nitrogenous fertilizers, they supplied most of the fertilizer phosphorus before 1875. Fish scrap, guano and animal tankage often contain more phosphoric oxide than nitrogen and practically all natural organics contain small amounts of phosphorus (Table 4-13). Normal superphosphate has been the principal source of fertilizer phosphorus since 1875, but ammonium phosphate, ground-rock phosphate, and triple superphosphate are gaining very rapidly in usage. (Table 4-10).

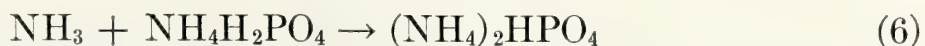
Jacob^{31, V} discusses phosphorus resources and processing facilities in detail.

Ammoniated Superphosphate. The acidity of superphosphate was first used commercially in 1927 to fix free ammonia. Now nearly all superphosphate used in mixed fertilizers is ammoniated. About 40,000 tons of anhydrous, 70,000 tons of aqua ammonia and 610,000 tons of solutions containing free ammonia were thus consumed in 1950. Together, these liquids supplied about one-third of all the nitrogen in mixed fertilizers.

Ammoniation of normal superphosphate, according to Keenen³⁴ results in the following successive reactions:



In concentrated superphosphate, which contains relatively little calcium sulfate, reactions (2) and (3) are followed principally by reaction (6):



Addition of more than 3 pounds of free ammonia per ton for each 1 per cent of phosphoric oxide present may result in reversion to citrate-insoluble phosphates. In practice up to 5 pounds have been used, but this may cause serious reversion unless the product is rapidly cooled and dried. See also Hardesty and Ross²⁶ and Jacob³¹.

Ammonium Phosphates. *Monoammonium phosphate*, $\text{NH}_4\text{H}_2\text{PO}_4$, containing an average of 11.80 per cent of nitrogen and 61.33 per cent of

phosphoric oxide, has been used in relatively small tonnages for many years, but most of the fertilizer ammonium phosphate has consisted of 11-48 and 16-20 grades, which contain approximately 10 and 45 per cent of ammonium sulfate, respectively. The 16-20 grade is also called "Ammophos B" and ammonium phosphate-sulfate.

Diammonium phosphate, $(\text{NH}_4)_2\text{HPO}_4$, has an economic advantage in that the phosphoric acid fixes twice as much free ammonia as the mono-salt, but the product, until recently, was unsatisfactory, because it loses ammonia easily. A satisfactory fertilizer, which contains 21 per cent of nitrogen and 53.6 per cent of phosphoric oxide, is made by coating the particles with monoammonium phosphate⁷³. A more recent product contains: N, 18; P_2O_5 , 46; SO_3 , 3.6; and F, 2 per cent.

Ammonium phosphate-nitrate is produced by ammoniating the solution separated from rock phosphate, that has been treated with an excess of nitric acid. It is a mixture of monoammonium phosphate and ammonium nitrate and averages 27.43 per cent nitrogen and 15.13 per cent phosphoric oxide.

Basic Lime Phosphate. This material was invented in 1900 as a substitute for basic slag. Since the development of ammoniated superphosphate its use has greatly decreased. Control officials⁸ require that it contain 6 per cent of calcium carbonate equivalents in excess of enough to convert all water-soluble phosphorus to citrate-soluble forms.

Basic Slag. Although other slags are used, the two principal fertilizer types are Bessemer and open-hearth basic slag. They are both relatively high in manganese (Table 4-14).

Bessemer or Thomas slag is a by-product of the production of steel from high phosphorus ore and dolomite. It is one of the chief sources of fertilizer phosphorus in Europe, but is relatively unimportant here.

Open-hearth slag is produced at Birmingham, Ala., in the manufacture of steel. It is used both as a liming material and fertilizer.

Bone Meal. Green bones contain too much fat to grind easily. Raw bone meal is, therefore, prepared from bones cooked in open kettles. A part of the gelatine has been removed from steamed bone meal by steaming under pressure.

Calcium-magnesium Phosphate. By fusing a mixture of rock phosphate with 30 per cent of magnesium oxide, or its equivalent in serpentine or olivine, the phosphorus is rendered soluble in 2-per cent citric acid. "M-P Phosphate" and "Thermophos," usually contain about 30 per cent of calcium oxide, 15.5 per cent of magnesium oxide, and 18 per cent of phosphoric oxide soluble in citric acid.

Calcium Metaphosphate. "Metaphos," $\text{Ca}(\text{PO}_3)_2$, is a glass produced by burning phosphorus in contact with phosphate rock. The present Ten-

nessee Valley Authority product averages 61.79 per cent phosphoric oxide soluble in citric acid.

Fused Tricalcium Phosphate. Fusing rock phosphate containing silica at 2700°F in an atmosphere of steam drives off most of the fluorine and converts the material into $\alpha\text{-Ca}_3(\text{PO}_4)_2$. It contains about 27 per cent available phosphoric oxide and 0.2 per cent fluorine.

High-grade Residue. The insoluble residue obtained as a by-product in the manufacture of sodium phosphate is chiefly gypsum, but contains from 6 to 8 per cent of phosphoric oxide.

Phosphate Rock. Mining of phosphate rock in this country started at Charleston, S. C., in 1867. Shipments from the Florida deposits began in 1888, from Tennessee in 1893, and from the Western deposits around 1920.

In 1950 producers sold or used 11,483,978 tons, of which 9,056,174 came from Florida, 1,550,610 tons from Tennessee, and the remainder from Idaho, Montana, and Wyoming. In the same year 6,800,973 tons were used to manufacture superphosphates, 958,606 were applied as such to soils, principally in Illinois and adjoining states, and 17,299 tons were used, mostly in Florida, as filler in mixed fertilizers.

Phosphate rock is sold on the wholesale market on the basis of its BPL (bone phosphate of lime) content. The usual grades range from 68 to 77 per cent of BPL, which may be converted to P_2O_5 by multiplying by 0.45764. All domestic phosphate rocks contain about 3.5 per cent of fluorine (Table 4-15). Florida land pebble contains sufficient uranium (about 0.01 per cent) to justify its recovery. The leached zone overlaying the pebble contains 0.02 per cent or more. At present the uranium can be recovered economically only by making phosphoric acid.

For details on composition not given in Tables 4-13, 4-14 and 4-15 see Hoffman and Lundell³⁰, Jacob *et al.*³² and Newton⁵⁸.

Phosphoric Acid. Two methods are employed commercially to produce this acid, H_3PO_4 . In the wet process, phosphate rock is treated with sulfuric acid and the dilute phosphoric acid produced is filtered off and concentrated by evaporation. In the other, rock, sand and coke are heated in an electric furnace to around 1500°C. The evolved phosphorus is burned to form P_2O_5 , which is absorbed in water to produce concentrated acid directly⁶⁵.

In the West, phosphoric acid is applied to alkaline soils as a separate fertilizer in irrigation water. It is also used in the manufacture of liquid mixed fertilizers. The usual guarantee is 52 or 53 per cent phosphoric oxide.

Precipitated Phosphates. A by-product of both glue and gelatine manufacture is produced by precipitating dicalcium phosphate, CaHPO_4 , with lime from the hydrochloric acid solution of bones. It is called precipitated bone and is used both as a feed supplement and as a fertilizer. It contains about 36.6 per cent available P_2O_5 .

TABLE 4-17. TONS OF AVAILABLE P_2O_5 SUPPLIED BY VARIOUS GRADES OF SUPERPHOSPHATES, AND PER CENT OF THE TOTAL, ALL USED SEPARATELY IN AGRICULTURE

Material	Year ended June 30, 1925		Calendar year 1941		Year ended June 30, 1952	
	P_2O_5 (Tons)	Part of Total (%)	P_2O_5 (Tons)	Part of Total (%)	P_2O_5 (Tons)	Part of Total (%)
Normal grades						
10 to 14%, inclusive	2,351	1.03	96	0.02	0	0
16-17	127,551	55.96	39,750	9.48	0	0
18-19	4,229	1.86	14,477	3.45	68,385	13.19
20	10,310	4.52	248,650	59.30	176,113	33.95
Total	144,441	63.37	302,973	72.25	244,498	47.14
Concentrated grades						
30-32	0	0	729	.17	1,654	.32
38-45	6,055	2.66	27,030	6.45	61,603	11.88
46-50	0	0	49,210	11.74	37,926	7.31
Total	6,055	2.66	76,969	18.36	101,183	19.51
All superphosphate	150,496	66.03	379,942	90.61	345,681	66.65
Other materials	77,439 ^a	33.97	39,389	9.39	172,990 ^b	33.35
Total in separate materials	227,935	100.00	419,331	100.00	518,671	100.00

^a A large part from organics such as bone meal, cottonseed meal, fish scrap, and animal tankage.

^b Largely from ammonium phosphates, basic slag, calcium metaphosphate, and rock phosphate (3% available).

"Fertiphos" is imported dicalcium phosphate made from rock phosphate. It may not legally be sold under the name precipitated bone⁸.

Superphosphates. Normal superphosphate consists of grades guaranteed to contain up to and including 24 per cent available phosphoric oxide, which is the highest grade that can be made with sulfuric acid alone. Concentrated superphosphate is any grade guaranteed to contain 25 per cent or more. For the past 50 years a steady trend toward the use of higher-analysis grades has been evident (Table 4-17). At many points near the coasts the 20-per cent grade is the cheapest per unit of phosphoric oxide; but at interior points 40- to 50-per cent grades are usually the most economical on a delivered-to-the-farmer basis.

Normal superphosphate is generally manufactured by a process, the details of which vary in different plants, but is about as follows. One ton of finely ground phosphate rock and 1800 pounds of 70-per cent sulfuric acid

are mixed in a cast iron pan, provided with paddles, an opening in the cover to discharge the liberated gases, and a valve in the bottom. After thorough mixing the liquid begins to thicken and is discharged through the valve into a curing den. By dilution the acid is heated to somewhere between 90 and 150°F depending on the circumstances and by reaction with the rock the slurry is heated still further. In the den the slurry rapidly solidifies and after a short time (usually 30 minutes to several hours) is removed to a storage pile for curing. Den superphosphate is porous like pumice due to the escape of steam and gases, such as hydrofluosilicic acid and carbon dioxide.

Equation (7) represents in a simplified form the reactions that occur:



where X may be F_2 , $(\text{OH})_2$, CO_3 or SiF_4 . This reaction seldom runs to completion even after curing and intermediate reactions, and other reactions due to the impurities, also occur.

Cured superphosphate roughly consists of the following substances in the proportions indicated: monocalcium phosphate, 26; dicalcium phosphate, 8; free phosphoric acid, 2; calcium sulfate, 50; moisture, 6; and other components; 8 per cent, respectively.

Production in 1950 was 9,296,051 tons, with an average run-of-pile P_2O_5 content of 19.43 per cent⁵. Consumption in the Continental United States in 1950 was 1,863,292 tons as a separate material, and 6,390,000 tons in the manufacture of mixed goods. Alaska, Hawaii and Puerto Rico used 62,000 additional tons.

The average available phosphoric oxide content of all grades increased from 11.01 in 1880 to 13.98 in 1900, then to 16.66 in 1920, to 18.87 in 1940, and to 20.09 per cent in 1950. At present practically the entire consumption as a separate material consists of 18-, 19- and 20-per cent grades. The actual P_2O_5 content of the average superphosphate exceeded the guarantee from 1940 to 1949 by 0.59 per cent.

Grade increases resulted from the use of washed and floated rock, more concentrated acid, better curing, a drier product, and to fortification with double superphosphate.

As the available phosphoric oxide increases, the calcium and sulfur contents also increase. Average 16-, 18- and 20-per cent superphosphate contain 25.80, 27.09 and 28.72 per cent of calcium oxide⁴⁴, and 25.56, 29.36 and 30.39 per cent of sulfur trioxide⁴⁸, respectively.

For further details on production and manufacture see Jacob and Shelton³³, Siems^{31, VI}, Shoeld, Wight, and Sauchelli⁷² and Adams, Tremearne, Jacob and Porter⁵. Additional details on composition are given by Jacob³¹, Hill *et al.*²⁹, and Mehring⁴⁷.

Concentrated superphosphate containing around 32 per cent of phosphoric oxide has been made in comparatively small quantities for a number of years with mixed sulfuric and phosphoric acids. Production of this grade will probably increase in the near future at the expense of 18 to 20 per cent superphosphate, because of the stimulating effect on phosphoric acid production of the uranium recovery program.

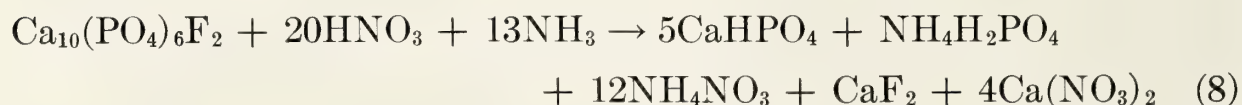
The bulk of the concentrated superphosphate production consists of 40- to 50-per cent grades, which are made with phosphoric acid. From 1872 until about 20 years ago 40-per cent grades were invariably known as double superphosphate, but recently they have been called triple superphosphate and other names.

Some manufacturers use 28 to 46 per cent acid, when the product must be artificially dried, which also granulates it. Other producers use 60 to 75 per cent acid, but 75 is the limit, because stronger acids do not react satisfactorily.

Consumption in 1950 was as follows: separate material, 279,650; in mixtures 358,000; in raising run-of-pile to 20-per cent superphosphate 60,000; and exports, 33,729 tons. See also Porter and Frisken⁶¹, Mehring⁴¹ and Siems^{31, VI}.

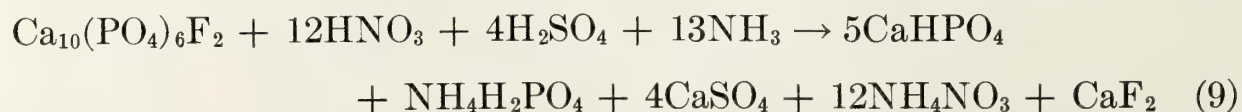
Nitric superphosphate is prepared by treating phosphate rock with nitric acid alone or mixed with sulfuric or phosphoric acid. It has been made on a large scale in Europe for about 30 years, but was first produced commercially in the United States in 1953.

A number of different procedures are used to avoid the presence of calcium nitrate, which makes the superphosphate too hygroscopic. A European process uses enough nitric acid to convert all the P_2O_5 in the rock into phosphoric acid. The solution is cooled, and after the precipitated calcium nitrate is centrifuged out, is ammoniated. The combined reactions are represented by Eq. (8):



The 20-20-0 superphosphate, relatively free of calcium nitrate, has good physical condition.

In another commercial process the product obtained with a mixture of nitric and sulfuric acids is ammoniated. The combined treatments may be expressed by Eq. (9):



This 14-14-0 superphosphate is about the same as the product of Eq. (8), except for its calcium sulfate content.

Other processes are also in use, but whatever the approach the product consists principally of dicalcium phosphate and ammonium nitrate^{31, VIII}. Nitric superphosphate is used to make high-analysis mixtures.

Wet-mixed base is a form of superphosphate prepared, as a rule, by treating a mixture of rough ammoniate and rock phosphate with sulfuric acid. Spoiled fish or meat, and at times dead animals are also salvaged in its manufacture. It is used almost exclusively as a component of mixed fertilizers.

Potassium

The earliest sources of fertilizer potash, K_2O , were wood ashes and salt-peter, but since 1874 it has come chiefly from natural brines and mineral salt deposits.

From 1874 until 1916 almost the entire supply for the United States was imported. Then World War I cut off imports and potash was produced from the brine of Searles Lake at Trona, Calif., and many other raw materials. Low prices of imports, resumed in 1919, caused all the domestic producers except the one at Trona, Calif., to cease operating.

In the vicinity of Carlsbad, N. M., layers of salt 4 to 12 feet thick were discovered that average from 14 to 30 per cent of potash. Shipments from this area started in 1931 and now supply the bulk of requirements in the United States^{31, VIII and IX}.

Potash is also produced from the brine of Salduro Marsh, Utah, from salt wells at Midland, Mich., and from cement flue dust. Most of the natural organics contain small amounts and tobacco stems are primarily a potash material (Table 4-13). Approximately 90 per cent of the 1,581,467 tons of fertilizer potash consumed in the year ended June 30, 1952 was in the form of mixed fertilizers⁷¹.

For more detail on the composition of potash salts than is given in Tables 4-13, 4-14 and 4-15, see Turrentine⁷⁵.

Cement Flue Dust. First used as a fertilizer in 1913 in California, this material now comes chiefly from Maryland and contains 2.5 to 11 per cent of potash and about 25 per cent of lime.

Kainit. Imports of kainit began in 1877 and from 1905 to 1913 averaged around a half million tons annually. Imports ceased in 1940. The mineral kainite, $KCl \cdot MgSO_4 \cdot 3H_2O$, is not found in mineable quantities in this country.

Manure Salts. Crude potash salt is usually a mixture of potassium and sodium chlorides and is called manure salts. Various grades with guaranteed potash contents from 20 to 30 per cent, inclusive, have been marketed. Over 90 per cent of the imports prior to 1931 were of a 20-per cent grade, but most of the domestic production has been 25-per cent material.

Potassium Chloride. The bulk of all potash in mixed fertilizers for many years has been supplied by this material, KCl, also known as muriate of potash.

Prior to 1922, only the 50-per cent grade was available, but in 1951 domestic producers shipped 1,735,047 tons of a 60- to 63-per cent material and only 155,896 tons of 50-per cent. Manufacturers of mixed fertilizers use 60-per cent or better material almost exclusively, because it is cheaper per unit. On the other hand about half of the tonnage bought separately by farmers is 50-per cent goods. Most farmers could also save money by using the 60-per cent grade.

The principal impurity is always sodium chloride. The salt from Michigan and Germany contains around 0.5 per cent of magnesium oxide, but other kinds contain little or none. Trona potassium chloride contains about 0.3 per cent of boron trioxide. Before 1931, the moisture averaged around 1.5 per cent, but the present domestic material generally contains less than 0.5 per cent.

Potassium-magnesium Sulfate. *Double manure salts*; as it was formerly named, was imported from Germany from 1887 until 1940. It consisted principally of leonite, $K_2SO_4 \cdot MgSO_4 \cdot 4H_2O$ and contained: K_2O , 25–29; MgO , 10–12; and SO_3 , 42–47 per cent.

“*Sul-Po-Mag*” is produced at Carlsbad by washing the rapidly soluble impurities out of the slowly soluble langbeinite, $K_2SO_4 \cdot 2MgSO_4$. It contains: K_2O , 20–23.5; MgO , 17–19, and SO_3 , 56–58 per cent.

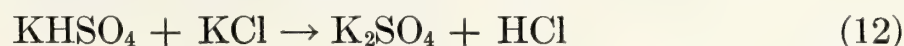
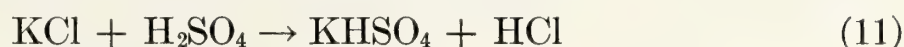
Potassium Nitrate. Saltpeter was the first chemical used as a fertilizer. For centuries it has been prepared from a composted mixture of wood ashes, garbage and urine. Such saltpeter containing from 50 to 90 per cent potassium nitrate (KNO_3) has been imported from India since 1850⁸¹.

Potassium nitrate imported from Germany is manufactured by passing nitrogen peroxide into a refrigerated solution of potassium chloride. It is used in the preparation of high-analysis fertilizer for potatoes and tobacco and in liquid fertilizers.

Potassium Sulfate. From 1875 until 1891 imports of potassium sulfate, K_2SO_4 , consisted largely of a 40-per cent grade, but since then of a 48- to 52-per cent material. The potassium sulfate produced at Marysvale, Utah, in 1915 from alunite was the first potash derived from a mineral source in the United States. During World War I, it was produced from cement flue dust and distillery wastes. Since 1938 it has been produced from the brine at Trona, Calif. It is also produced from langbeinite at Carlsbad according to Eq. (10):



Another process is based on the following equations:



Equation (12) is endothermic and must be carried out in a salt-cake furnace.

Most of the combined sales in 1950 of 273,000 tons of potassium sulfate and "Sul-Po-Mag" was used in growing tobacco.

Sodium-Potassium Nitrate. This material, also known as "Nitrapo," is prepared in Chile by working up the mother liquors from which sodium nitrate has been crystallized. As much as 60,000 tons were used in the United States in one year, mostly as a top-dressing for citrus trees, but relatively little has been imported since World War II.

Tobacco Stems. Ground midribs of tobacco leaves have been used as fertilizer since about 1865, but since 1914 a large part of the production has first been extracted for nicotine. Comparatively small tonnages of extracted stems are used as mushroom soil. Unextracted stems are also used as a combination insecticide and fertilizer in greenhouses. Since 1940 the total consumption has exceeded 100,000 tons annually.

The mean N, P_2O_5 and K_2O contents of 206 samples of untreated stems are 2.08, 0.61, and 6.79 per cent, and of 60 samples of extracted stems are 1.52, 0.60, and 4.68 per cent, respectively.

Wood Ashes. In 1880, 2,555,000 tons of wood ashes was produced in home cooking and heating and most of it was spread on gardens or fields⁴⁰. At present, production on farms is less than one million tons annually. Only four to five thousand tons are handled by the fertilizer industry, mostly for use on tobacco in New England.

The potash contents of pure ash vary from 10 for soft woods to 40 per cent for hard woods, but due to the presence of dirt, charcoal, and moisture, crude ashes usually run from 3 to 9 per cent. Home fires yield around 35 pounds of crude ash per cord of wood burned. Twenty samples of ashes leached by falling rain contained on the average only 1.20 per cent of potash.

Unleached wood ashes, as compared with fertilizers in general, always contain generous amounts of the secondary and trace elements (Table 4-14). The boron trioxide content of 36 samples of crude ash from many different localities varied from 0.02 to 1.01 per cent, with an average of 0.48.

Calcium

Special provision for calcium as a fertilizer is seldom necessary, because of the large tonnages of liming materials (Table 4-4) and gypsum (Table 4-10) applied to soils, and also because all manures (Table 4-2) and most commercial fertilizers (Table 4-14) contain calcium as secondary constituents.

Ordinary superphosphate contains more calcium than phosphorus. Of 485 tested samples of mixed fertilizers, representative of all types and all important grades used from 1930 to 1948, only 3 contained less than 3 per cent calcium oxide⁴⁴. The weighted average calcium oxide content of all mixed fertilizers used in 1946 on the basis of the tonnage of each grade sold is 18.69 per cent. Very concentrated fertilizers, however, may be lacking in calcium. Table 4-18 shows the quantities applied to soils in different forms.

Magnesium

With the decrease in the use of kainit and natural organics the average magnesium oxide content of fertilizers dropped from 1.15 in 1900 to 0.72 per cent in 1930. Then magnesium deficiency symptoms in crops began to be recognized. As a result dolomite, magnesia, kieserite, and other magnesian materials were added to mixed fertilizers, and dolomitic limestone was substituted for calcic limestone as a liming material in many areas⁴⁰. Many mixed fertilizers in the Atlantic Coastal States now are guaranteed to contain from 2 to 5 per cent magnesium oxide, but others, bearing no such guarantees, may contain little or none⁴⁵.

In 1950 and 1952, 28,615 and 31,579 tons, respectively, of magnesium oxide as actual magnesia, calcined kieserite, or epsom salts, were used as fertilizer³⁷.

Table 4-18 shows the quantities applied in different classes of soil improvement materials.

Sulfur

Relatively little material is applied to the soil specifically to provide nutrient sulfur, but enormous tonnages become available to plants, nevertheless. Several of the most important fertilizers, for example, superphosphate, ammonium sulfate and potassium sulfate are high in sulfur content (Table 4-14). The quantities applied in several forms are indicated in Table 4-19).

The burning of fuels and industrial operations give off sulfur in the form of SO_2 , SO_3 and H_2S gas into the atmosphere in large quantities. These gases also contribute to the sulfur nutrition of plants in the area⁴⁸.

Most of the 20,000 tons of elemental sulfur applied annually to soils is used in the far west. It is mixed into commercial fertilizers as well as applied separately. The mean sulfur contents of the principal types employed are: Frasch-process sulfur, 99.60 ± 0.04 ; volcanic sulfur, 66.67 ± 2.66 and sulfur earth, 29.88 ± 0.98 per cent.

Sulfuric Acid. Three and one-half million tons of sulfuric acid, H_2SO_4 , are used annually to manufacture fertilizers. Fresh acid manufactured by the lead-chamber and contact processes, and spent acid from various other

TABLE 4-18. CONSUMPTION OF CALCIUM^a AND MAGNESIUM^b OXIDES IN THE FORM OF MANURES, LIMING MATERIALS, AND FERTILIZERS, IN CERTAIN YEARS 1900 TO 1950
(1000 tons)

Calendar year	Manures		Liming Materials		Fertilizers		Total ^c	
	CaO	MgO	CaO	MgO	CaO	MgO	CaO	MgO
1900	1,717	901	417	51	463	48	3,462	1,086
1910	1,786	983	568	58	895	79	3,976	1,190
1920	2,131	1,069	1,053	107	1,070	65	5,132	1,328
1930	1,903	960	1,465	186	1,264	61	5,214	1,264
1935	1,931	960	1,354	216	1,007	86	5,027	1,321
1940	1,984	992	4,934	1,070	1,362	109	8,930	2,231
1945	2,272	1,082	9,316	1,838	2,531	190	14,744	3,155
1950	1,995	943	11,647	2,263	3,933	225	18,175	3,471

^a See Mehring⁴⁴ for additional data.
^b 1910-45, Mehring⁴⁵. The data for 1900 and 1950 were obtained in the way described in the earlier publication.
^c Larger than the sum of the 3 quantities itemized because the total also includes the quantities from seaweed, peat, composts and wood ashes from home fires. The quantities derived from gypsum and phosphate rock in 1950, are included with fertilizers. Prior to that they are in the totals only.

TABLE 4-19. ESTIMATED QUANTITIES OF SULFUR APPLIED TO SOILS BY CLASS OF MATERIALS, DECENNIAL YEARS 1850 TO 1950^a
(1,000 tons of SO₃)

Calendar year	Primary nutrient fertilizers	Other fertilizers ^b	Liming materials	Manures	Misc ^c	Sum of preceding ^d
1850	1	52	2	282	51	389
1860	6	65	3	348	66	488
1870	35	69	3	410	82	599
1880	100	61	3	512	92	768
1890	211	52	8	713	78	1,062
1900	494	39	11	751	73	1,368
1910	903	31	13	810	67	1,824
1920	1,230	53	16	917	88	2,304
1930	1,591	32	18	852	160	2,653
1940	1,521	68	63	796	225	2,673
1950	3,186	248	41	868	360	4,703

^a Mehring and Bennet⁴⁸, except 1950. The earlier publication gives data annually 1925-48.
^b Gypsum, sulfur, manganese sulfate, etc.
^c Insecticides, fungicides, wood ashes from home fires, greensand marl and other materials.
^d Does not include that from the atmosphere, which is derived from burning sulfur containing fuels, natural gas, smelting of sulfide ores and other sources.

industries, for example, petroleum refining, are employed both to make superphosphates and to reclaim alkali soils. For details of manufacture see Fairlie²⁰.

Gypsum

Large quantities of crude gypsum, or land plaster, were applied as fertilizer throughout the Atlantic Coastal Region in colonial times, but this practice declined after the introduction of superphosphate. Its uses in growing peanuts in the Southeastern States and in reclaiming alkali land in the West have increased in recent years (Table 4-10).

Table 4-14 gives the average composition of land plaster. See Adams³ for information on material from different deposits. By-product gypsum from phosphoric acid manufacture contains on the average: CaO, 30.6; SO₃, 43.2; P₂O₅, 1.8; and F, 0.5 per cent.

Trace Elements

The fertilizers commonly used to supply trace elements are borax, and copper, ferrous, maganese, and zinc sulfates. Their properties are given in Table 4-11 and their composition in Table 4-14.

For soils in which the above salts are rendered unavailable, or where rapid leaching exists, powdered glasses or frits are also used. These insoluble silicates contain from 5 to 10 per cent of one of the desired elements in an available, but very slowly soluble, form.

The following quantities of minor nutrients were consumed in 1952 in the Continental United States: boron, 1,544; copper oxide, 5,601; ferrous oxide, 260; manganese oxide, 4,712; and zinc oxide, 2,499 tons. Boron was used in many states, but the others were consumed largely in Florida. Additional quantities of ferrous sulfate were used in both Hawaii and Puerto Rico. For consumption by states and earlier years see Lowe³⁷.

Mixed Fertilizers

About two-thirds of the total fertilizer consumption consists of commercial mixtures. Table 4-20 shows the quantities used in certain years, with the average grade (N-available P₂O₅-K₂O contents). The composition of various types of mixed fertilizers are given in Tables 4-13, 4-14, 4-15 and 4-21.

Types of Mixed Fertilizers. Mixtures guaranteed to contain specified percentages of nitrogen, phosphoric oxide, and potash (N-P-K mixtures) comprised 89 per cent of the 15,086,349 tons of all types used in the 1951-52 season. P-K mixtures constituted eight, N-P mixtures two, and N-K mixtures 1 per cent of the total. Liquid mixtures and those with additional guarantees on other nutrients are included in the above.

N-P-K mixtures were introduced about 1874 as a substitute for Peruvian

TABLE 4-20. CONSUMPTION^a OF COMMERCIAL MIXED FERTILIZERS AND THEIR AVAILABLE NUTRIENT CONTENTS

Calendar year	Thousand Tons				Percentages			
	Mixed fertilizers	N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O	Total nutrients
1880	350	8	32	7	2.4	9.1	2.0	13.5
1890	800	18	74	17	2.3	9.3	2.1	13.7
1900	1,771	35	166	44	2.0	9.4	2.5	13.9
1910	3,437	72	320	117	2.1	9.3	3.4	14.8
1920	4,062	93	374	97	2.3	9.2	2.4	13.9
1930	5,616	174	550	281	3.1	9.8	5.0	17.9
1940	5,513	209	531	358	3.80	9.63	6.49	19.92
1941	5,844	223	566	391	3.82	9.68	6.70	20.20
1942	6,837	253	665	477	3.69	9.72	6.98	20.39
1943	8,316	272	858	589	3.27	10.32	7.09	20.68
1944	8,713	337	899	606	3.87	10.32	6.95	21.14
1945	9,254	367	951	694	3.96	10.27	7.50	21.73
1946	11,159	434	1,166	800	3.88	10.45	7.17	21.50
1947	11,909	476	1,257	836	4.00	10.56	7.02	21.58
1948	12,266	493	1,323	900	4.02	10.78	7.34	22.14
1949	12,271	489	1,323	983	3.99	10.78	8.01	22.78
1950	13,033	530	1,433	1,111	4.06	11.00	8.52	23.58
1951	14,127	592	1,566	1,283	4.19	11.09	9.08	24.36
1952 ^b	15,086	648	1,681	1,420	4.30	11.14	9.42	24.86
1953 ^b	15,722	728	1,782	1,554	4.63	11.34	9.88	25.85

^a The data include Alaska, Hawaii, and Puerto Rico, and government distributed fertilizers.

^b Year ended June 30⁷¹.

guano⁵². The average grade in 1875 was 2.3-8.9-2.2 and remained approximately the same until 1915. It has changed considerably, however, since then (Table 4-20). Table 4-21 gives the complete composition of several kinds. The N-P-K mixtures are dominant in all states except those in the Rocky Mountains.

P-K mixtures are primarily legume fertilizers. In order to prevent the free acid of the superphosphate in this type from destroying bags and liberating hydrochloric acid from the potash, it is customary to add lime or limestone. For this reason they are known as alkaline grades in some states. Many P-K mixtures contain from 10 to 50 pounds of borax per ton.

N-P mixtures are the principal type in semiarid regions. Some of the so-called N-P mixtures are merely ammonium phosphate or ammoniated superphosphate.

N-K mixtures are used mainly for top dressing in the Southeast and Puerto Rico. The 14-0-14 grade is sometimes just sodium-potassium nitrate.

High-analysis mixtures are those containing 30 per cent or more of N, P₂O₅ and K₂O combined. Sales of such grades in the Continental United

TABLE 4-21. COMPOSITE ANALYSES OF MIXED FERTILIZERS, BY TYPE, GRADE AND YEAR OF PRODUCTION

Constituent	N-P-K							P-K
	General Purpose Fertilizers					Tobacco	Florida Citrus	Legume
	10-18 ^a , 1900-09 (%)	14-21 ^a , 1930-39 (%)	14-22 ^a , 1940-49 (%)	24-40 ^a , 1927-35 (%)	45-68 ^a , 1928-47 (%)	15-20 ^a , 1947 (%)	18-24 ^a , 1948 (%)	14-28 ^a , 1926-50 (%)
Nitrogen								
Ammoniacal	0.39	2.06	2.87	4.83	8.29	1.71	2.67	0.01
Nitrate	.38	0.58	0.56	0.39	1.94	0.64	1.47	.00
Soluble or- ganic	.35	.27	.27	.24	1.47	.38	0.30	.02
Insoluble	1.14	.72	.32	.33	0.18	.68	.65	.04
Total	2.26	3.53	4.02	5.79	11.88	3.41	5.09	.07
Phosphoric oxide								
Available	9.17	9.54	10.36	18.26	29.52	9.06	6.95	12.16
H ₂ O-soluble	5.86	5.03	5.01	9.47	27.03			5.92
Citrate, soluble	3.31	4.51	5.35	8.79	2.49			5.24
Insoluble	2.30	0.71	0.83	0.46	0.35	0.53	3.15	0.70
Organic	1.74	.52	.21	.00	.00			.00
Total	11.47	10.25	11.19	18.72	29.87	9.59	10.10	12.86
K ₂ O	3.21	5.36	7.06	10.76	12.14	6.27	7.40	11.68
Na ₂ O	3.75	3.49	1.65	3.78	5.23	2.00	2.00	2.44
CaO	15.43	15.49	16.62	10.88	4.75	17.02	14.02	19.33
MgO	1.78	1.65	2.07	1.05	1.07	2.53	3.84	1.96
R ₂ O ₃	0.97	1.54	1.46	1.35	1.24	1.55	1.93	1.87
CuO	.01	0.027	0.03	0.012	0.026	0.006	0.29	0.04
MnO	.03	.076	.08	.020	.102	.05	.39	.08
ZnO	.03	.041	.04	.053	.042	.010	.067	.03
Cl	5.63	5.50	5.72	7.88	3.91	2.34	3.61	7.99
CO ₂	0.01	1.76	3.10	1.06	0.37	4.99	4.25	2.73
SO ₃	15.13	18.67	19.31	17.26	9.70	17.43	16.50	17.92
B ₂ O ₃	0.03	0.021	0.03	0.023	0.024	0.008	0.013	0.174
F	.81	.71	.67	.67	1.02	.65	.60	.97
SiO ₂	7.17	13.92	10.95	3.61	0.49	12.25	9.51	17.44
Organic matter	19.78	8.54	6.67	2.54	4.30	12.25	12.00	0.40
H ₂ O	10.24	6.27	4.07	5.00	4.60	6.61	5.69	4.45
Number of samples	b	27	b	8	5	b	39	8
Literature citation	47	38	47	38	38-47	46	47	47

^a The total guaranteed content of N, available P₂O₅, and K₂O. The range is both inclusive.

^b Estimated from thousands of analyses in state fertilizer analysis bulletins and tonnages and average composition of materials used in that period to make mixed fertilizers. The data should be approximately the means for the conditions shown.

States increased from 17,554 tons in the year ended June 30, 1917, to 1,083,720 in the 1950, and over 1,990,000 in the 1952 fiscal year.

The cost of factory labor, bags, and freight in 1953 was about \$20.00 per ton of mixed fertilizer and this has to be prorated against the cost of the nutrients whether they are 16 or 60 per cent of the weight. High-analysis mixtures usually require the use of somewhat more expensive phosphatic materials, but even after the manufacturer has passed their cost along to the consumer, the delivered-to-the-farm price per unit of nutrient is usually less. For example, on Sept. 15, 1953, the average of retail prices in the United States on 2-12-6 and 4-24-12 fertilizers were \$43.50 and \$77.70 per ton. One-half ton of 4-24-12 contains the same quantities of each primary nutrient as a whole ton of 2-12-6, and should contain sufficient amounts of other nutrients, if properly made. The cost, however, is \$38.85 or 10.7 per cent less. The purchaser of the 4-24-12 also has less work to do.

Large-scale production of nitric superphosphate and recovery of uranium as a valuable by-product may possibly make the cost of phosphatic materials for high-analysis mixtures as cheap as those for low-analysis grades. The most economical sources of nitrogen and potash already are used to make the high-analysis mixtures.

The first high-analysis mixtures on the market contained from 60 to 70 per cent total nutrients and their use on light sandy soil was often unsatisfactory. It is believed that these results were chiefly due to their almost complete lack of secondary and trace nutrients. Table 4-21 shows that high-analysis mixtures sold more recently do contain these elements. See also "Nitrophoskas" in Tables 4-13, 4-14 and 4-15. It is practicable to make mixtures containing from 30 to 40 per cent primary nutrients from present-day materials and have room for inclusion of other necessary nutrients. See also Lockwood^{31, XIII}.

Liquid mixed fertilizers were introduced around 1935 in Southern California for convenient application in irrigation water. They are also sold on a small scale in the East for use in overhead irrigation systems and as starter solutions for addition to the water in transplanting machines. Liquid fertilizers are on the market from Texas to California in practically all the grades popular as dry mixtures.

Grades. The most popular grades sold in the year ended June 30, 1953, are shown in Table 4-22. Although 10 grades accounted for 51.1 and 117 grades for 97.5 per cent of the total consumption, more than thirteen hundred grades were on the market. This table includes all grades of which over 90,000 tons were sold in the 1952-53 season.

By comparing the percentages for the same grade in different years it may be observed that in general grades that are increasing in tonnage sales contain 21 or more per cent of total primary nutrients, whereas those that

TABLE 4-22. PERCENTAGE OF THE TOTAL CONSUMPTION OF MIXED FERTILIZERS IN CONTINENTAL UNITED STATES OF THE PRINCIPAL GRADES IN THE YEAR ENDED JUNE 30, 1953, AS COMPARED WITH PREVIOUS FISCAL YEARS

Grade	1934	1939	1944	1949	1950	1951	1952	1953
3-12-12	0.11	0.38	2.01	7.72	10.15	13.50	15.41	14.50
5-10-10	.07	.36	2.24	3.64	3.71	4.29	5.83	7.22
5-10-5	.67	1.06	6.12	7.89	7.25	6.58	6.13	5.68
3-9-6			8.76	6.57	6.49	6.28	5.40	4.34
4-10-6	.15	0.54	5.34	6.43	5.17	4.53	4.20	3.76
4-10-7	.31	.65	0.17	3.33	3.21	3.41	3.43	3.41
4-8-6	1.41	2.67	4.47	4.87	4.65	4.29	3.59	3.11
3-12-6	0.41	1.28	4.13	6.83	6.67	5.34	4.47	3.10
4-16-16				0.21	0.37	0.89	1.45	3.06
3-9-9			0.79	1.76	2.28	2.56	2.75	2.95
2-12-12	.02	0.06	.10	1.26	1.65	2.35	2.72	2.65
10-10-10				0.12	0.27	0.53	0.94	2.59
8-8-8			.14	.58	0.74	1.08	1.93	2.21
4-8-8	.83	1.95	1.97	1.73	1.84	1.94	1.78	2.14
0-20-20	.06	0.21	0.07	0.54	0.97	1.59	1.56	1.97
6-8-8	.03	.27	.02	.93	1.40	1.60	1.82	1.77
0-14-14		.03	.31	.28	.99	1.72	2.22	1.72
6-8-6	.11	.24	1.55	2.20	2.38	1.93	1.78	1.55
6-8-4	.03	3.10	5.64	3.31	2.39	1.91	1.56	1.39
4-12-12				0.13	0.17	.24	.56	1.32
4-12-4	1.71	1.72	4.46	4.41	3.60	2.67	1.67	1.24
6-12-12				0.03	0.26	0.59	0.92	1.07
4-12-8	0.04	0.13	1.66	2.09	2.30	1.78	1.46	1.04
2-12-6	3.68	8.62	16.51	10.45	7.31	4.31	2.15	1.01
3-9-18	0.08	0.16	0.51	0.95	1.07	1.49	1.24	1.00
4-7-5	.64	.97	1.48	.88	0.98	0.87	0.81	0.85
0-12-12	.18	.47	1.70	1.99	1.08	1.06	1.29	.80
10-20-0			0.06	0.15	0.28	0.44	0.57	.78
3-9-27					.05	.17	.54	.76
3-18-9		.20	.23	1.15	1.28	.87	.73	.74
8-24-8	.05	.02	.04	0.01	0.11	.28	.43	.69
All other	89.41	74.91	29.52	17.56	18.93	18.91	18.66	19.58

are declining in importance contain 21 or less. The same trends are shown by all grades, as is illustrated in Figure 4-5.

Ingredients. The quantities of the various materials used in manufacturing commercial mixtures in 1950 are listed in Table 4-10. A typical 5-10-5 fertilizer can be made up about as follows:

Material	lbs/ton
Ammonium sulfate	91
Ammoniating solution	200
Superphosphate	1,025
Potassium chloride	164
Conditioner	200
Filler	320
Total	2,000

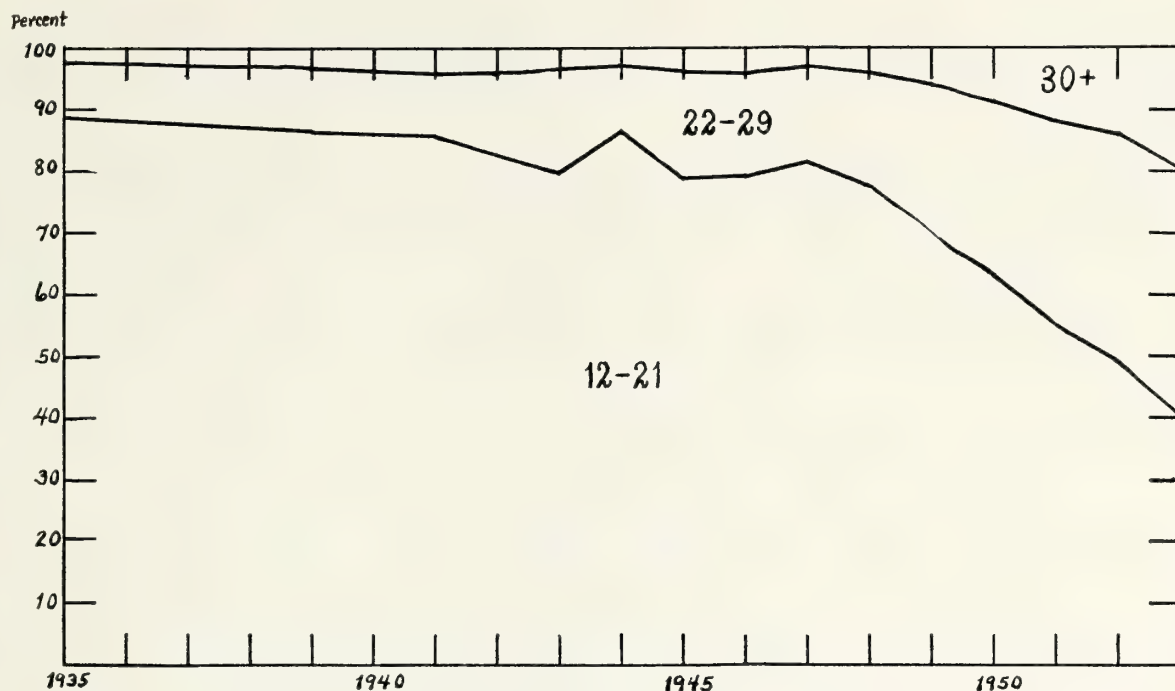


Figure 4-5. Proportions of the total consumption of mixed fertilizers consumed in continental United States represented by grades, with the percentages of total primary nutrients indicated.

Other quantities of the above materials would be used for most N-P-K grades totaling less than 24 per cent nutrients. For special-purpose mixtures, however, or because of local economic conditions, many other materials are also employed, such as potassium sulfate, magnesia, borax and gypsum.

As a rule manufacturers use the most economical materials available to their plant which serve the required purpose. Although calcium metaphosphate and fused phosphates are economical and efficient under certain conditions for separate application, they are not economical for mixtures, because they cannot be ammoniated.

For higher-analysis grades ammonium nitrate, potassium nitrate, urea, ammonium phosphate, triple superphosphate, or nitric superphosphate might be substituted in whole or in part for ammonium sulfate and/or normal superphosphate and the quantity of filler would be reduced.

Liquid fertilizers must be free of sediment in order to be applied satisfactorily with customary farm equipment. Superphosphates are therefore not satisfactory sources of phosphorus for liquids, and ammonium phosphate, potassium phosphate, or phosphoric acid are used instead.

Conditioners are finely divided insoluble substances, like peat, fuller's earth or cocoa shells, that reduce the tendency of chemical fertilizers to harden in the bag. They function by absorbing moisture and by coating the fertilizer particles, and thus prevent them from sticking together. Hardesty and Kumagai²⁵ tested 54 different conditioners and concluded that none was invariably satisfactory.

In general, either drying an ordinary fertilizer mixture to 1.5 or less per

cent moisture content, or granulation, and packing in moisture-proof bags does more to insure satisfactory drillability than the addition of conditioners.

Filler is sand, ground phosphate rock or any material that is added to a fertilizer mixture to make weight and round out the formula for a given grade. Thus a conditioner, or dolomite, which is normally added to make a nonacid-forming fertilizer, may also be used as a filler. The impurities and elements in combination with the nutrients in fertilizer materials are not filler⁴³.

In recent years the average mixed fertilizer has contained 5 to 6 per cent sand. Inasmuch as some contain none, others must have had excessive amounts. A small amount (2 or 3 per cent) of make-weight material is justifiable to adjust formulas to desired grades, but if excessive amounts are required it is better to change the grade. For instance, if the 320 pounds of filler were left out of the 5-10-5 formula given above, the other materials would make 1,674 pounds of 6-12-6 grade. The latter would be worth just as much to the farmer, but should cost less.

Segregation. Mixtures composed of materials, whose particles vary considerably in size, shape, or specific gravity tend to segregate during handling⁵³. Such fertilizers, even though well mixed, many become progressively less uniform in composition during piling, bagging, shipping, and distribution on the land¹⁶. In other words every time such a mixture is disturbed it segregates some more. Some commercial mixtures segregate seriously, but most of them do not.

Samples of segregated mixtures upon analysis may not conform with the guaranteed grade, and thus cause the state control official to assess penalties against the manufacturer.

The experiment stations have spent much time and money in attempts to learn the best combination of nutrients for specified crops on various soil types. Their recommendations do little good, however, if a farmer buys a recommended grade and it segregates, for then individual plants will not receive the right balance of nutrients for best results.

Granulation. Various procedures are employed to granulate a mixed fertilizer. The essentials of these processes are about as follows: the raw materials are ground to pass a 4- or 5-mesh screen, wetted to a moisture content of 6 to 15 per cent, cascaded in a rotary cylinder or stirred in a pan, dried, and screened to desired size of particle. The coarse particles are cracked and the fines are reprocessed. Most of the particles of the product should contain all nutrients. When the mixture is ammoniated little or no other water is necessary and the heat of reaction is often sufficient to dry the product.

Granulated mixed fertilizers were used to grow cotton in 1930 and found

to be superior in a number of respects to powdered materials^{17, 53}. Other conditions being the same, granular mixtures are much less likely to cake, do not segregate, are not dusty, flow more uniformly from most farm distributors, and are more pleasant for the operator. With their use the distributor is easier to clean and corrodes less. Uniformity of distribution increases crop yields⁵⁰.

The use of granular fertilizers was very slow in getting started, but is now growing rapidly. About 45 plants will manufacture granular mixtures in 1954 as compared with 20 in 1952. It is estimated that 10 per cent of the total production in 1954 will be granulated. See also Chucka^{31, XII} and Taylor^{31, XI}.

Curing. Fertilizer mixtures usually solidify and become undrillable during storage, because the chemicals react to form new compounds. At ordinary temperatures in a relatively dry state these reactions are slow and require much time to establish equilibrium.

Curing consists of storing the mixture until the caking reactions are about complete. Then after grinding and screening the fertilizer will remain drillable until used, provided it is not too hygroscopic. Hygroscopic salts cause another type of caking, which is discussed under drillability.

Heat and the presence of free water hasten curing. Both of these conditions are provided by ammoniation with solutions of ammonia. The addition of a very small amount of a surface active agent is claimed to hasten curing and to produce softer products. Both satisfactory and disappointing results have been reported from the use of surfactants and unbiased conclusions as to the conditions for excellent results do not now seem possible.

One type of reaction that causes caking during curing is chemical drying, in which the salts combine with water to form hydrates. Many salts do not form hydrates, but cured superphosphate always contains some. Hydrates often present in cured mixed fertilizers are $\text{CaHPO}_4 \cdot 2\text{H}_2\text{O}$, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, and $\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}$. Temperatures above 140°F tend to prevent hydration or to release free water from hydrates already formed, but the hydrates will reform upon cooling.

Special-Purpose Mixtures. Physiologically basic or nonacid-forming mixed fertilizers are produced in large tonnages by adding dolomite. They are used in areas where the soils are very acid and the soil is not adequately limed. It would be more economical in many cases, however, to apply the dolomite to the soil directly and buy a somewhat higher analysis grade of fertilizer.

Some very acid-forming fertilizers on the other hand are used on alkaline soils or for use in growing acid-loving plants on soils not sufficiently acid. They contain free sulfur, aluminum sulfate or other acid-forming material.

Special mixtures are also prepared to combine fertilizer action with the

control of weeds, insects, fungi, or other pests and for other special purposes^{31, XIV}. These include lawn fertilizers containing DDT to kill Japanese beetles and 2,4-D to control weeds. Farm fertilizers are being used in considerable tonnages that contain chlorinated hydrocarbons for simultaneous fertilization and control of corn rootworms or sand wireworms.

Fertilizer Control

There is no federal law regulating the sale of ordinary fertilizers, but those containing added pesticides must be registered with the U. S. Department of Agriculture. All States, however, require registration, guarantees of nutrient contents, payment of fees or taxes, and compliance with other provisions for all fertilizers sold within their borders. Fertilizer year books give the name and address of the control official for each State^{1, 2}.

Inspectors collect samples for chemical analysis and fertilizers not complying with the law result in penalties against the manufacturer. A small over-run of the guarantee is customary, and is considered good policy by most manufacturers. The results of analyses, tonnages of the different kinds and grades of fertilizers consumed, and much related information are published in annual bulletins by most States. Detailed directions for making the tests and analyses are published in the "Book of Methods" of the Association of Official Agricultural Chemists⁹. Definitions and regulations governing the enforcement of state fertilizer laws are issued by the Association of American Fertilizer Control Officials⁸.

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5. INSECTIDES, FUNGICIDES AND HERBICIDES

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Introduction

The use of insecticides, fungicides and herbicides to control agricultural pests does not represent an ideal situation. We are, however, confronted with the necessity of using such pesticidal compounds in order to produce sufficient quantities of a marketable quality of foods and fibers. In 1820 approximately 70 per cent of this country's population worked in agriculture. In 1950 this figure had declined to 15 per cent despite the increased demands for agricultural products. In addition, the required heavier cropping and more specialized varieties of plants which, according to Martin¹ are more adversely affected by the activities of other organisms, have presented serious challenges to agricultural enterprises.

Although insects tend to make themselves known to most of our population, the full extent of their damage is not so obvious. Insect damages have been estimated at 4 billion dollars². This value is nearly matched by the even less obvious losses from plant diseases which total 3 billion dollars annually³. Weeds, like insects, are familiar to a vast majority. By definition, a weed is any plant growing where not wanted. The toll collected by such plants is estimated to be greater than the combined losses from insects, plant diseases and animal diseases⁴.

The tax imposed by these agricultural pests is a potent stimulus to discover more efficient methods of reducing our share cropping activities with such burdensome partners. The value of mechanical, cultural and and biological control practices is not to be discounted in combatting these pests. Despite efforts along these lines, we find that in 1935 more than 215 million pounds of pesticidal chemicals were used. By 1944 the consumption of these compounds had doubled, and in 1951 more than one billion

pounds of pesticidal chemicals were required. Such quantities of materials with the attendant application costs could not be employed unless they were necessary for crop production.

Since 1944 more than 25 major new pesticidal compounds have been made available commercially. The Pesticide Regulation Section of the U. S. Department of Agriculture has registered for use and labelling over 30,000 pesticidal formulations. The need for such a vast array of pesticidal chemicals may be more apparent when we realize that at least 3,000 species of insects and twice as many diseases attack crops. To consider just one crop, the apple grower has to compete with about 200 infectious diseases and 100 insect pests in order to produce a marketable crop.

The chemicals used in combatting these pests are designated as economic poisons and are subject to the provisions of the Federal Insecticide, Fungicide and Rodenticide Act of 1947. This law was enacted "... to regulate the marketing of economic poisons and devices and for other purposes." Since many of these pesticidal compounds are used in such a manner that they are associated with foodstuffs or other materials ultimately destined for consumption by man, they are also subject to the Federal Food, Drug and Cosmetic Act of 1938. This latter act is the subject of another chapter, which should be consulted for further information.

Each crop situation represents a separate environmental condition with such factors as weather conditions, soil types, specific tolerances, marketing conditions, etc., to be considered⁵. Each pesticidal chemical has specific advantages and limitations which must be evaluated in making the proper selection. In addition to the toxicant, there are many other components of the dust or spray application which must be taken into account. With the complexities of the environmental situations of these three categories of agricultural pests, and the large number of pesticidal compounds already available, it is impossible to adequately treat all aspects of their properties and uses in a limited space. New pesticidal compounds are being developed constantly, making even a detailed account incomplete with the arrival of the next mail.

In this chapter only a small sample of the total number of pesticidal compounds are given general consideration. These compounds represent both old and new materials. The names used in the tables are common names wherein they appear to be well established. Structural formulas are used as much as possible so as to indicate chemical relationship more readily. Literature references for the various compounds are noted in each table in addition to the few specific citations in the text and the list of general references. These texts have been freely consulted in the process of compiling the information presented in this chapter. Detailed information and more complete bibliographies are available in the texts cited.

Formulation and Application

Although the actual toxicant is the primary concern of this chapter, the action of the toxicant is to a large extent influenced by the formulation and method of application employed for each specific case. In general, with the exception of the fumigants and repellents, most pesticidal chemicals are applied as dusts, sprays or aerosols.

The effective toxicities of most of these compounds are such that they must be applied in a greatly diluted form in order to be used both economically and safely. The toxicant must be distributed over the treated area as uniformly as possible. It must be applied in such a manner that it contacts the pest or is deposited on areas subject to an infestation by the pest. The toxicant must be available to the pest organism over a period of time sufficient to effect its control. Control is usually accomplished by the elimination or reduction of an established population or by preventing the establishment of an undesired population.

The carrier or diluent and the other components employed in a formulation should not increase the hazards coincident with the use of the toxicant, such as mammalian toxicity, phytotoxicity, corrosion, abrasion, or fire hazard, etc. They should not render the toxicant less effective for either physical or chemical reasons.

In the use of dusts for pesticidal application the following are some of the factors to be considered: (1) particle size and shape, (2) specific gravity, (3) electrostatic charge, (4) adhesive qualities, (5) flowability when formulated with the toxicant or toxicants being used, and (6) adverse effects on the application equipment. The inert carrier in dusts usually poses few problems with reference to mammalian toxicity or phytotoxicity. Dusts are, however, more subject to wind drift and, therefore, may be more hazardous from the standpoint of contaminating adjacent cropped areas. Since uniform deposits are desirable, such drift makes dust applications impractical in many areas with persistent winds.

Water is one of the more common carriers employed in pesticidal sprays. Due to the relative insolubility of many pesticidal chemicals in water, they are used as emulsions or suspensions. Various surface active agents are employed in spray formulations to aid in emulsification, spreading, sticking, etc. Wettable powders are representative of the suspension type of application. The solvents and surface active agents employed in many sprays may complicate the problems of mammalian and phytotoxicity.

In some cases various organic solvents, including oils, are used as carriers for pesticidal applications, particularly where a residual effect is desired and phytotoxicity is not a hazard. The pest under consideration and the general environmental situation play a major part in determining the type of formulation best suited for each situation.

Droplet size is of considerable importance in spray applications. Droplet size is usually determined by the size and shape of the orifice and the pressures employed in the spray machinery. Haller⁶ discusses the subject of insecticide particles and their effects on insecticide action. The principles of this subject can readily be applied to the situations presented by the use of fungicides and herbicides.

The selection of the proper type of application equipment has much to contribute to the successful use of pesticidal chemicals. This subject is, to a large extent, a field unto itself, calling for contributions from entomologists, chemists, engineers, and to a very major extent in recent years, aeronautical engineers and pilots. Application equipment ranges from the traditional flit gun to multiple engine aircraft and helicopters.

There is still a further general problem that must be considered. In many cases, in view of economy of operations, it is desirable to make pesticidal applications containing several toxicants, i.e., an insecticide and fungicide. In such cases it is necessary to consider the matter of compatibility. This problem involves the possibilities of adverse chemical reactions, physical incompatibility, etc. An example of such incompatibility is DDT and lime sulfur.

The frequency and amount of pesticidal application may be important factors. Dunegan⁷ has an interesting observation in this respect, "We have noted time and again in our experimental work that multiple applications of weak or sublethal doses have given more instead of less disease even though the quantity of material applied per season remained the same. The peach growers in the South experienced great difficulty in 1953 in controlling the peach scab fungus. In some cases it appeared that repeated applications of a weak mixture aggravated the scab problem." Such occurrences add emphasis to the need for careful, continuing investigations of potential pesticidal chemicals and application methods.

Insecticides

The traditional classifications for insecticidal compounds has been that of stomach, contact and fumigant poisons, based on their mode of entry into the insect. The method followed in this chapter is to group these compounds according to chemical composition, origin, or in certain cases, their specific uses; i.e., fumigants, repellents, etc. No attempt is made to supply a complete list of compounds or to provide specific data as to their chemical, physical or biological properties. Although general areas or methods of use are indicated in the tables, there is no implication that the subject compounds are effective throughout the spectrum of pests. A compound indicated for field crop use does not imply that it is effective for all insect pests of field crops or safe for use on all such crops.

From the historical view, the inorganic and botanical compounds have a priority. Despite the rapid influx of synthetic organic compounds in recent years, many of these older insecticides have not been completely replaced. It is difficult to establish a starting point for the use of chemicals to control insects. Arsenic compounds were employed against garden insects by the Chinese as early as 900 A.D. One of the first of the widely used insecticidal botanical derivatives appears to have been nicotine. Preparations from tobacco plants were employed around 1690. Sabadilla, however, antedates the other botanicals as records indicate its use in the latter part of the sixteenth century.

Although DDT is perhaps the most spectacular synthetic organic insecticide, the thiocyanates were first offered commercially in 1929 to 1930, about fifteen years before the advent of DDT. In volume, the arsenicals were the most widely used. The production of lead arsenate in the United States reached a peak in 1944 with more than 90 million pounds. In 1948, two years after the introduction of DDT, lead arsenate production had declined to about 24 million pounds.

Inorganic Insecticides. Only seven inorganic compounds are listed in Table 5-1. Until the introduction of DDT and subsequent synthetic organic compounds, the inorganic insecticides constituted the main line of chemical defense against agricultural pests. In general, these compounds exerted their lethal action after entry through the digestive system of the insect. Repeated and frequent applications of these materials were usually required in order to obtain a reduction of insect damage. The arsenates of lead and calcium have been the most widely used. Because of their unique physical properties and generally broader spectrum of insecticidal action, these compounds will continue to find limited use as insecticides, although they have been largely replaced by more recent

TABLE 5-1. INORGANIC INSECTICIDES

Name	Formula	Areas of use	State contro- lled	Type of use	Met- hod of ap- plica- tion	Pharmaco- logy	Ref.
Sodium fluoride	NaF	G	KL	N	R	AII CII	9, 10
Barium fluosili- cate.....	BaSiF ₆	BC	JKL	MN	RS	AII CII	11, 12, 13, 14
Cryolite.....	Na ₃ AlF ₆	ABCD	JKL	MN	RS	AIII CIII	14, 15, 16
Calcium ar- senate.....	Probably 3Ca ₃ (AsO ₄) ₂ · Ca(OH) ₂	ABC DFG	JKL	MN	RS	AII CI	17, 18, 19, 20
Lead arsenate...	PbHAsO ₄	ABCD	JKL	MN	RS	AII CI	21, 22, 23
Paris green.....	(CH ₃ COO) ₂ Cu·3Cu(AsO ₂) ₂	ABC DFG	JKL	MN	RS	AII CI	24, 25
Lime sulfur.....	Calcium polysulfides	BDF	JKL	MN	S	AIII CIII	26, 26a

CODE: *Areas of Use:* Field crops, A; Horticultural crops, B; Truck crops, C; Ornamentals, D; Stored products, E; Livestock, F, Household, G. *Stage Affected:* Egg, H; Larva, J; Nymph, K; Adult, L. *Type of Use:* Direct spray or dust, M; Residue, N; Systemic, O, Fumigant, P. *Method of Application:* Dust, R; Spray, S; Aerosol, T. *Pharmacology:* Chronic, C; Acute, A. *Order of Hazard:* I, High; II, Moderate; III, Low.

compounds. Certain arsenic compounds also find considerable use as herbicides.

The inorganic fluorine compounds find application against both household and agricultural insects. Sodium fluoride is widely used as a roach poison (about 3 million pounds annually) and for poultry lice. With the recent and continuing occurrence of chlordane resistant German roaches, Heal *et al.*⁸, the use of sodium fluoride baits is receiving renewed emphasis. The fluosilicates have found considerable application in insect baits, although they have been largely replaced by the chlorinated organic compounds such as toxaphene. They have also been used extensively as moth-proofing agents. Cryolite was used as a replacement for lead arsenate during World War II. In 1944 over 15 million pounds of cryolite were consumed as an insecticide. Cryolite has been largely replaced by DDT and other synthetic organic compounds.

Lime sulfur and Paris green have long been classical insecticidal compounds; like the other inorganics, their insecticidal application has been considerably reduced by more recent developments.

Insecticides of Botanical Origin. The majority of these compounds are relatively unstable, particularly as contrasted to the chlorinated organic insecticides. The botanical insecticides are generally very effective as direct contact insecticides. Only nicotine demonstrates any fumigant properties. With the exception of pyrethrins, these compounds are also toxic to insects by ingestion. Their relative instability under many conditions of use renders this latter route of intoxication somewhat ineffective. The structures listed in Table 5-2 are not the sole toxic ingredients occurring in the various plants, but do represent the major toxic constituents.

Rotenone and pyrethrins have found widespread use in the control of insects attacking man and animals. Their lack of mammalian toxicity or general irritation under most conditions of use makes them particularly valuable. In 1946 over 20 million pounds of pyrethrum flowers and powders and 11 million pounds of rotenone-bearing materials were imported by the United States. Although nicotine, which possesses a rather high order of mammalian toxicity, does not find the same areas of usefulness as rotenone and pyrethrins, approximately 1½ million pounds were consumed as insecticides in 1943. The rapid development of synthetic insecticides is responsible for a sharp decline in the use of these compounds.

With the exception of nicotine, obtained from domestic plants of the genus *Nicotiana*, the botanicals are derived almost exclusively from imports. Pyrethrins are obtained from plants of the genus *Chrysanthemum*. In 1948 most of our imports were obtained from British East Africa and the Belgian Congo, as contrasted with 1934 when by far the major source was Japan. Rotenone is obtained from leguminous plants, the genera

Tephrosia, *Derris*, *Lonchocarpus* and *Millettia* representing the more important sources. In recent years the major source has been from Latin American countries. Rynania is obtained from plants of the genus *Rynania*, found principally in South America. Venezuela is the primary source of sabadilla, obtained from the genus *Schoenocaulon*.

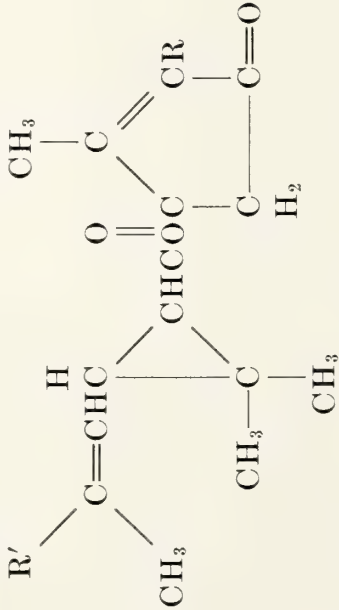



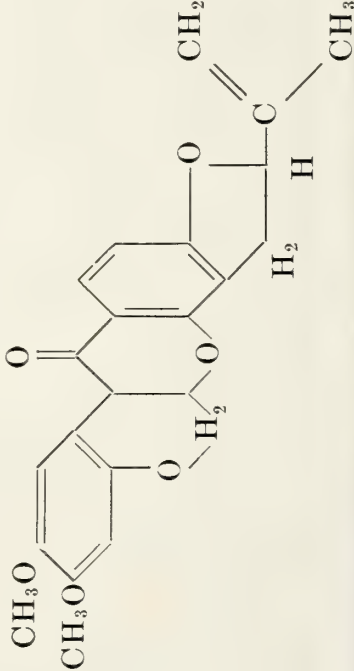
In discussing these compounds of botanical origin, it is desirable to consider the phenomena of synergism. A synergist is "A chemical which when added to an insecticide gives a product with greater killing power than the insecticide by itself. The added chemical may or may not have insecticidal properties²⁷." Although such a definition may not be entirely satisfactory, it serves to describe the effects of several compounds used in connection with pyrethrins and allethrins. Some of these compounds are listed in Table 5-3. Combinations of such synergists and pyrethrins not only result in a more toxic material, but also a toxic combination which may be effective over a greater period of time. In this respect, such compounds also appear to act as stabilizers, retarding the normal degradation of the toxicant. The exact manner in which these synergists act upon the toxicant or insect has not been determined.

In recent years synergists have been sought for other compounds, particularly for use with DDT against resistant flies. A general review of the use of synergists by Sumerford²⁸ has recently appeared. Synergists for use with other types of compounds will be considered later.

Chlorinated Organic Insecticides. Paradichlorobenzene was first patented in the United States as an insecticide in 1914. One of its major uses has been for clothes moth control. Pentachlorophenol was first produced commercially in 1936. Its insecticidal uses are primarily as a protective agent against the attacks of termites, powder post beetles, etc. DDT is by far the most spectacular of all the chlorinated organic insecticides. The insecticidal properties of DDT were discovered in the laboratories of J. R. Geigy, A-G, Basel, Switzerland, by Dr. Paul Müller, a chemist, to whom in 1948 the Nobel Prize in medicine was awarded in recognition of this achievement. Although DDT was first synthesized by Zeidler in 1874, its insecticidal properties were not discovered until about 1939. Results of wide-scale tests with DDT in the United States were made public in 1944. The first year of DDT production in 1943 resulted in 250,000 pounds. By 1947, production had exceeded 47 million pounds. Following 1947 there was a brief decline in DDT production, but by 1952 over 90 million pounds of DDT were produced in the United States.

DDT was the predecessor of the majority of the compounds listed in Table 5-4. Benzene hexachloride was the next compound to come into wide-scale use. Its production rose from less than 10 million pounds in 1947 to over 80 million pounds in 1952. It is of interest to contrast these

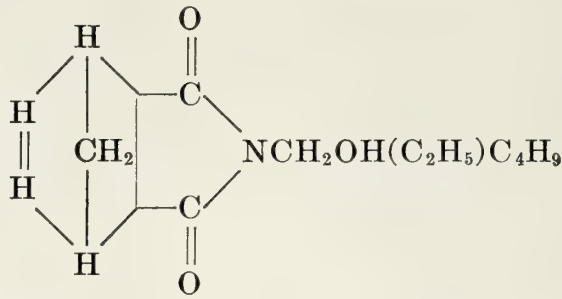
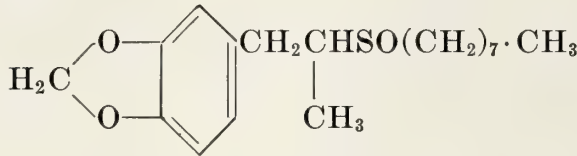
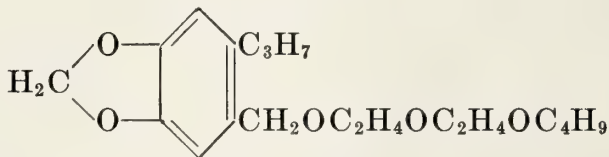
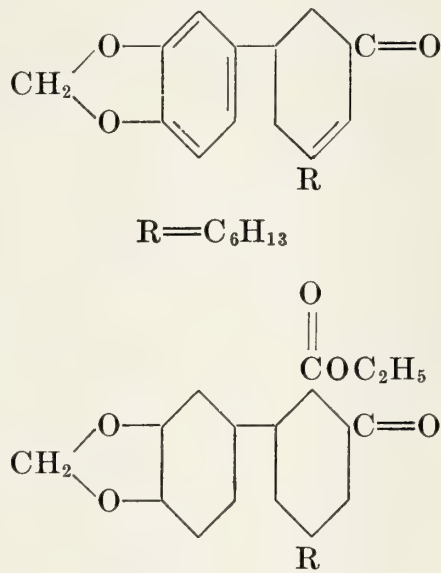
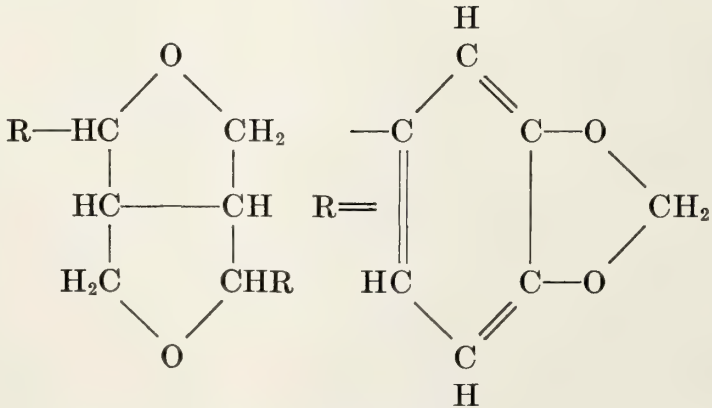
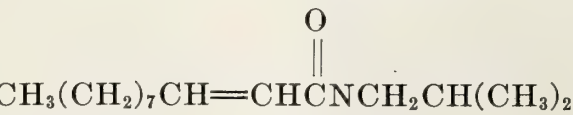
TABLE 5-2. INSECTICIDES OF BOTANICAL ORIGIN

Name	Formula	Major area of use	Stage controlled	Types of use	Applica- tion	Pharmacology	Ref.
Pyrethrins		DEFG	JKL	MN	RST	AIII CIII	29, 30, 31
Pyrethrin I Cinerin I							
Pyrethrin II							
Cinerin II							
Rotenone		CDFG	JKL	MN	RS	AIII CIII	32, 33, 34, 35

Nicotine		BCD	HJKL	MP	RS	AI CIII	36, 37, 38, 39
Sabadilla	A mixture of veratrine alkaloids	BCDG	JKL	MN	RS	AII CIII	40, 41, 42
Ryania	Ryanodine	AB	JKL	MN	RS	AIII CIII	43, 44

CODE: *Areas of Use*: Field crops, A; Horticultural crops, B; Truck crops, C; Ornamentals, D; Stored products, E; Livestock, F; Household, G. *Stage Affected*: Egg, H; Larva, J; Nymph, K; Adult L. *Type of Use*: Direct spray or dust, M; Residue, N; Systemic, O; Fumigant, P. *Method of Application*: Dust, R; Spray, S; Aerosol, T. *Pharmacology*: Chronic, C; Acute, A. *Order of Hazard*: I, High: II, Moderate; III Low.

TABLE 5-3. COMPOUNDS WHICH ACT AS SYNERGISTS WITH PYRETHRINS

Name	Formula	Ref.
MKG 264		45, 46
Sulfoxide		47
Piperonyl butoxide		48, 49, 50, 51
Piperonyl cyclonene	 <p style="text-align: center;">$R = C_6H_{13}$</p>	52, 51, 48
Sesamin		53, 54, 55
N-isobutyl undecyl-enamide		56, 57

figures with those of lead arsenate. There was a peak production of over 90 million pounds of lead arsenate in 1944. By 1952 its production had declined to a little over 10 million pounds.

Five of the compounds in Table 5-4 are very closely related to DDT. In general, DDT and its relatives have a very low water solubility. They are effective both as contact and stomach poisons. Their volatility is so low that no fumigant effect is observed. These compounds are not effective against all species of insects. Although the most spectacular use of DDT has been in the control of disease-transmitting insects and in general against insects attacking man and animals, its use in crop protection has also been extensive. The acute mammalian toxicity of DDT and its relatives is not excessive; the chronic toxicity, and more particularly the persistence of residues (desirable on the one hand), present potential hazards. It is by consideration of the compounds in this category that it is obvious that each compound has special characteristics that may render it invaluable under certain circumstances, while it may be inferior under other situations.

Benzene hexachloride and its purified gamma isomer, Lindane, represent still another type of chlorinated organic insecticide. These compounds are sufficiently volatile to have a fumigant action. This volatility is one factor leading to a shorter residual persistence.

Chlordan is the predecessor of another series of insecticides. These compounds are also relatively stable. Chlordan is sufficiently volatile to possess a fumigant action. Chlordan and its relatives are also insoluble in water, but like the other chlorinated insecticides, soluble in a wide range of organic solvents.

Most of the chlorinated organic compounds have been widely used for the control of house flies and mosquitoes and other insects of medical importance. It is perhaps this use that has earned them so much public attention. In recent years there have been numerous cases where it has been impractical to control houseflies with DDT. Repeated and extensive laboratory and field studies have indicated that house flies may become resistant to these compounds. Similar reports exist for mosquitoes and other public health insects. There are indications that a few agricultural insects may be acquiring a tolerance for these compounds.

This phenomena makes it quite evident that, while we may hold our own in the control of agricultural pests, there will be very little time to sit back and admire our handiwork. Detailed information on the phenomena of insecticide resistance will be found in papers by Babers⁵⁸ Babers and Pratt⁵⁹, Chadwick⁶⁰, and Decker and Bruce⁶¹ to cite but a few. The search for new compounds or combinations for use against insecticide resistant insects is represented by the work of March *et al.*^{61a} where over

TABLE 5-4. CHLORINATED ORGANIC INSECTICIDES

Name	Chemical name or formula	Major areas of use	Stage controlled	Types of use	Application	Pharmacology	Ref.
DDT	<chem>Clc1ccc(cc1)C(Cl)(c2cc(Cl)cc2)C3=CC=CC=C3Cl</chem>	A-G	JKL	MN	RST	AIII CI	62a, 63, 64, 65, 66, 67
Methoxychlor	<chem>COc1ccc(cc1)C(OC)(c2cc(OC)cc2)C3=CC=CC=C3OC</chem>	A-G	JKL	MN	RST	AIII CII	67, 68, 69, 70
TDE (DDD)	<chem>Clc1ccc(cc1)C(Cl)(C(Cl)Cl)c2cc(Cl)cc2</chem>	A-D	JKL	MN	RS	AI CII	67, 71, 72
Dilan	<chem>Clc1ccc(cc1)C(Cl)(C(=O)O[N+](=O)[O-])R</chem> <p> R=C₂H₅ 3 parts R=CH₃ 1 part </p>	CBA	JL	MN	RS	AIII CII	73

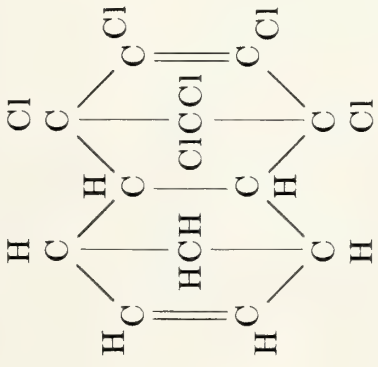
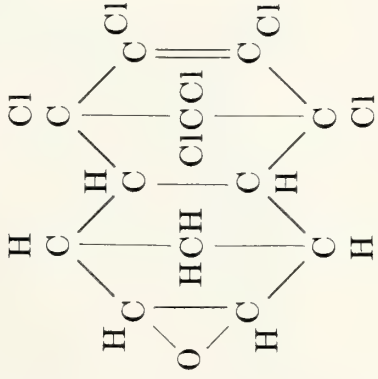
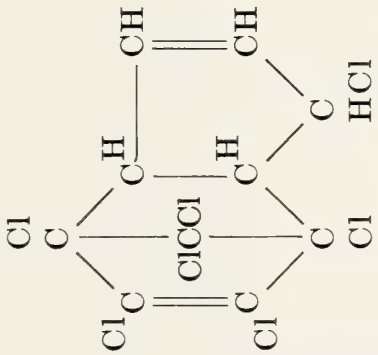

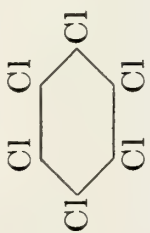


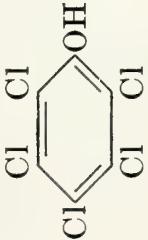
Chlordan	1, 2, 3, 4, 5, 6, 7, 8, 8-octachloro-2, 3, 3a, 4, 7, 7a-hexahydro-4, 7-methanoin-dene and related compounds	A-G	JKL	MN	RST	AII CI	74, 75, 76, 77
Aldrin		A-G	JKL	MN	RS	AI CI	77, 78, 79, 80
Isodrin	A stereoisomer of aldrin		JKL	MN	RS	AI C	81, 82
Dieldrin		A-G	JKL	MN	RS	AI CI	82, 79
Endrin	A stereoisomer of dieldrin	A	JKL	MN	RS	AI C	81, 82

TABLE 5-4—Continued

Name	Chemical name or formula	Major areas of use	Stage controlled	Types of use	Appli- cation	Pharmacology	Ref.
Heptachlor		A-G	JKL	MN	RS	AI CI	67, 83
Benzene hexachloride	 12-14% gamma isomer	ADF	JKL	MNP	RS	AII CII	67, 84
Lindane	 99% gamma isomer	A-F	JKL	MNP	RST	AII CII	67, 84, 85, 86
Toxaphene	C ₁₀ H ₁₀ Cl ₈ A mixture of chlorinated terpenes	AC	KL	MN	RS	AI CII	67, 87, 88, 89, 90

<i>o</i> dichlorobenzene		A-G	H-L	NP	RS	91, 92, 93
<i>p</i> dichlorobenzene						
Pentachlorophenol		E	JKL	MN	S	94

CODE: *Areas of Use*: Field crops, A; Horticultural crops, B; Truck crops, C; Ornamentals, D; Stored products, E; Livestock, F; Household G. *Stage Affected*: Egg, H; Larva, J; Nymph, K; Adult, L. *Type of Use*: Direct spray or dust, M; Residue, N; Systemic, O; Fumigant, P. *Method of Application*: Dust, R; Spray, S; Aerosol, T. *Pharmacology*: Chronic, C; Acute, A. *Order of Hazard*: I, High; II, Moderate; III Low.

TABLE 5-5. ACARICIDES

Name	Formula	Use	Ref.
Dimite		Pronounced ova- cidal action	96, 97
Neotran		Persistent con- tact action	98, 99
Aramite		Limited acaricidal action. Low phytotoxicity	100, 101
Ovatran		Pronounced re- sidual ovacidal action	102
Sulphene		Residual and ova- cidal action. Limited insecti- cidal action	102
Azoben- zene		Weak insecticidal activity. Usu- ally volatized from greenhouse steam pipes	103, 104
Dimetan		Limited acaricidal activity. Prom- ising as an aphidicide	105

90 compounds were investigated as potential synergists for DDT. Some of these compounds are also being investigated for their chemotherapeutic value in the control of livestock insects⁶².

Acaricides. Although these compounds could well be fitted into

other categories, they are grouped together because of their rather specialized uses. Despite the fact that mites, properly speaking, are not insects, their control does fall within the province of the economic entomologist. It might be well to refer here to a broad definition of insect, such as is used in the Insecticide, Fungicide and Rodenticide Act of 1947, "The term insect means any of the numerous small invertebrate animals generally having the body more or less obviously segmented, for the most part belonging to the class insecta, comprising six-legged, usually winged forms, as, for example, beetles, bugs, bees, flies and to other allied classes of arthropods whose members are wingless and usually have more than six legs, as, for example, spiders, mites, ticks, centipedes and wood lice."

Many of the compounds listed in Table 5-5 bear a close resemblance to DDT, yet their effectiveness is restricted to mites. They have, in general, little or no insecticidal value. As with the insecticides, these compounds may have an effect on one life stage and be totally ineffective against other life stages. There is also considerable specificity against different species of mites. Although DDT and Dimite are rather similar, the work of Metcalf⁹⁵ indicates that DDT is ineffective against mites while Dimite represents an effective acaricide. This work also demonstrated the marked specificity of a series of acaricides.


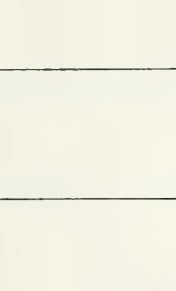

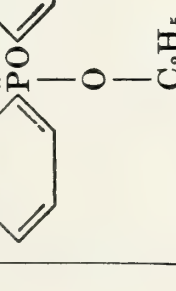
Organic Phosphorus Insecticides. The development of these compounds as insecticides is apparently a result of Schrader's investigations of chemical warfare agents in Germany during World War II. Three of the organic phosphorus compounds to be commercially available by 1948 were parathion, hexaethyl tetraphosphate and tetraethyl pyrophosphate (TEPP). The compounds in this category range from very unstable and completely water-soluble to very stable with a low water solubility. Despite the very high acute mammalian toxicity of some organic phosphorus compounds, they have been employed extensively as insecticides. Over 4 million pounds of parathion were produced in 1952.

TEPP is perhaps the most toxic to mammals, with an acute LD_{50} of about 1 mg/kg. Parathion has an LD_{50} of about 5 mg/kg, while the LD_{50} for malathion is of the order of 750 mg/kg¹⁰⁶. Thus far there has been little evidence of chronic intoxication with the organic phosphorus compounds such as is observed with DDT. All of these compounds are potent anticholinesterase materials. Their general extreme acute toxicity indicates that they should be handled carefully by trained personnel.

As insecticides, the compounds in Table 5-6 are generally effective as both contact and stomach poisons. Compounds such as parathion may remain effective from one to several weeks after application. TEPP, on the other hand, has a very brief effective period following application. Many of the organic phosphorus compounds are also effective as acaricides. It is

TABLE 5-6. ORGANIC PHOSPHORUS INSECTICIDES

Common name	Chemical name or formula	Major areas of use	Stage controlled	Types of use	Appli- cation	Pharmacology	Ref.
TEPP	$\begin{array}{c} \text{O} \quad \text{O} \\ \parallel \quad \parallel \\ (\text{C}_2\text{H}_5\text{O})_2\text{POP}(\text{OC}_2\text{H}_5)_2 \end{array}$	BCD	JKL	M	RST	AI CIII	110, 111, 112
Sulfotepp	$\begin{array}{c} \text{S} \quad \text{S} \\ \parallel \quad \parallel \\ (\text{C}_2\text{H}_5\text{O})_2\text{POP}(\text{OC}_2\text{H}_5)_2 \end{array}$	BCD	JKL	M	ST	AI CIII	113
HETP	A mixture of ethyl-polyposphates containing 10-20% TEPP	BCD	JKL	M	ST	AI CIII	112
Parathion	$\begin{array}{c} \text{S} \\ \parallel \\ (\text{C}_2\text{H}_5\text{O})_2\text{PO} \end{array} \text{C}_6\text{H}_4\text{NO}_2$	ABCD	JKL	MN	RST	AI CIII	67, 114, 115, 116, 117
Methyl parathion	$\begin{array}{c} \text{S} \\ \parallel \\ (\text{CH}_3\text{O})_2\text{PO} \end{array} \text{C}_6\text{H}_4\text{NO}_2$	ABCD	JKL	MN	RS	AI CIII	118
Malathion	$\begin{array}{c} \text{S} \quad \text{O} \\ \parallel \quad \parallel \\ (\text{CH}_3\text{O})_2\text{P} \text{SCHCOC}_2\text{H}_5 \\ | \\ \text{CH}_2\text{COC}_2\text{H}_5 \\ \parallel \\ \text{O} \end{array}$	ABCD	JKL	MN	RS	AIII CIII	119, 120
Schradan (OMPA)	$\begin{array}{c} (\text{CH}_3)_2\text{N} \quad \text{O} \quad \text{O} \quad \text{N}(\text{CH}_3)_2 \\ \diagup \quad \parallel \quad \diagdown \\ \text{POP} \\ \diagdown \quad \parallel \quad \diagup \\ (\text{CH}_3)_2\text{N} \quad \text{O} \quad \text{O} \quad \text{N}(\text{CH}_3)_2 \end{array}$	ABCD	JKL	O	ST	AII CIII	121, 122, 123, 124, 125, 126

EPN		A-D	JKL	MN	S	AI CIII	127, 128, 129
Demeton (Systox)		A-D	JKL	MOP	S	AI CIII	130, 131, 132
Diazinon		F	L	MN	S	AII CIII	133
Potosan		BC	LJ	MN	RS	AII CIII	134

CODE: Areas of Use: Field crops A, Horticultural crops B, Truck crops C, Ornamentals D, Stored products E, Livestock F, Household G. Stage Affected: Egg H, Larva J, Nymph K, Adult L. Type of Use: Direct spray or dust M, Residue N, Systemic O, Fumigant P. Method of Application: Dust R, Spray S, Aerosol T. Pharmacology: Chronic C, Acute A; Order of Hazard: I High, II Moderate, III Low.

of interest to note that several cases of mites resistant to parathion have been reported in the literature. Although these compounds have not been used extensively for house fly control, several attempts to develop house fly resistance to these compounds under laboratory conditions have failed to produce serious levels of tolerance.

Systemic compounds have been an ideal in pest control for many years. Certain selenium compounds were found to be effective in limited areas, but due to their persistence and extreme toxicity, cannot be used on food plants. Many of the organic phosphorus compounds are of considerable value as systemics. This term has been applied to any compound that is readily absorbed by a growing plant and translocated in an amount sufficient to render the plant toxic to insects that feed on it. This definition could easily be extended and modified to apply to fungicides and herbicides. Schradan and Demeton are among the most promising systemic insecticides currently available for use against plant feeding insects. Several new compounds are being explored for their potential systemic value. A bibliography of systemic insecticides has recently been published by Giang¹⁰⁷. The use of systemic compounds to combat external bloodsucking parasites is a promising field. The work of Knipling *et al.*¹⁰⁸ indicates some of the earlier work in this field. A paper by Hoffman¹⁰⁹ indicates a search for synergists that may be used with the organic phosphorus compounds.

Miscellaneous Organic Insecticides. The compounds listed in Table 5-7 are grouped here since they represent types of compounds not directly related in structure or usefulness to other categories. It was earlier pointed out that the thiocyanates represent the first successful synthetic organic insecticides. In addition to their lethal action, such compounds as the lethanes possess a paralytic or knockdown action similar to pyrethrins. These compounds are primarily contact insecticides, having little or no residual value.

The dinitro-cresols and related compounds find their principal use as dormant sprays for overwintering forms, particularly scale insects and eggs. The compounds are phytotoxic even at low concentrations. They also stain fabrics, woodwork, etc., which is a further objection to their general use.

Pyrolan represents another type of compound which has some limited uses. This compound also inhibits cholinesterases. Several carbamates of this type have been explored for their acaricidal effects.

Allethrin is a synthetic compound similar in structure and insecticidal action to pyrethrins. Announcements of its synthesis were first made in 1949. Production in 1951 was of the order of 50,000 pounds. Estimates of future production were in excess of 600,000 pounds per year. The insecticidal uses and limitations are similar to those of pyrethrins.

In many cases oils are thought of primarily as solvents for insecticides, despite their rather widespread use as direct toxicants themselves. Pearce *et al.*¹³⁵ discuss the use of petroleum oils as insecticides. Due to their tendency towards phytotoxicity, many oils are used as dormant sprays.

Fumigants. Fumigation for insect control may be divided into three broad categories: commodities, warehouses and greenhouses, etc., and soil. There are other specialized applications for the compounds listed in Table 5-8, but the above general categories represent the major areas. In the use of fumigants for insect control, it is necessary to rely on the toxicant reaching the insect in the vapor phase. This adds a further hazard to their use. Under such circumstances it is necessary to consider the possibilities of fires and explosions in addition to mammalian toxicity. The use of carbon dioxide with fumigants has an obvious advantage of reducing fire hazards. There is also the possibility that the levels of carbon dioxide employed will act as an initial respiratory stimulant, enhancing the more rapid inspiration of toxic gases.


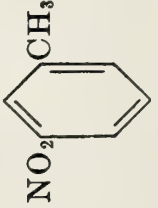
Many means have been employed to enhance the action of fumigants. The subject of vacuum fumigations has been discussed by Back and Cotton¹⁴⁵. Vacuum fumigation continues to find widespread use in certain areas.

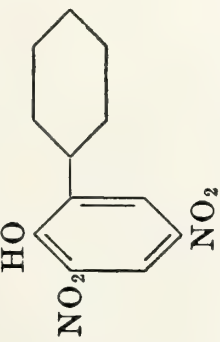
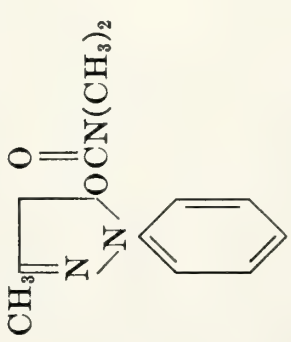
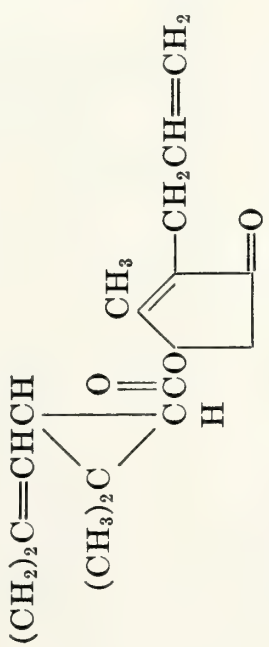
In the use of fumigants, consideration must be given to other possible adverse effects of their use such as phytotoxicity, etc. Certain of the fumigants listed in Table 5-8 also find considerable usefulness in soil fumigation, not only for insect control, but for weed control. Each situation where fumigants may or must be used calls for a careful evaluation of the characteristics of various compounds that may be used in relation to the details of the specific problem under consideration. With the increasing quantities of materials in storage to serve as a backlog against periods of high demand, it is necessary that methods for protecting such commodities against insect damage be improved. Although fumigation is not the sole means of obtaining such protection, it is widely used at the present time.

Repellents and Attractants. The use of chemicals to control insects is usually thought of as a process of eliminating the insect before the damage is initiated or consummated. The use of repellents depends on keeping the insect away from his site of attack or permitting only such a brief contact that no damage results. Attractants are, as the word might imply, employed to direct the attention of a pest to a specific area, either for purposes of contacting a lethal agent at such a site or, in earlier attempts, to lure him away from an area where he might inflict damage.

The use of chemical attractants and repellents extends far back into history. The earlier attempts were rather like most primitive efforts, employing various ill-defined concoctions (usually equally ill smelling).

TABLE 5-7. MISCELLANEOUS ORGANIC INSECTICIDES

Name	Chemical name or formula	Major areas of use	Stage controlled	Types of use	Applica- tion	Pharmacology	Ref.
Thanite	<div><div><div>CH₃</div><div>O</div><div>OCCH₂SCN</div></div><div></div></div>	FG	L	M	S	AIII CIII	136, 137
Lethane 384	C ₄ H ₉ O(CH ₂) ₂ O(CH ₂) ₂ SCN	ABC DFG	HKL	M	S	AIII CIII	138
Lethane 60	<div><div>O</div><div>||</div><div>RCO(CH₂)₂SCN</div><div>R=C₁₀H₂₁ to C₁₈H₃₇</div></div>	ABC DFG	HKL	M	S	AIII CIII	138
Lauryl thio- cyanate	CH ₃ (CH ₂) ₁₀ CH ₂ SCN	BD	H-L	M	S	AIII CIII	139
DNOC	<div><div>HO</div><div></div><div>NO₂</div></div>	BD	HJKL	MN	S	AII CII	140, 141, 142

DNOCPH		BD	HJKL	MN	RS	AII CII	141, 142
Pyrolan		FG	KL	MN	RS	AI CII	143
Allethrin (synthetic pyrethrin-like compound)		DEFG	JKL	MN	RST	AIII CIII	144

Code: Areas of Use: Field crops, A; Horticultural crops, B; Truck crops, C; Ornamentals, D; Stored products, E; Livestock, F; Household, G. Stage Affected: Egg, H; Larva, J; Nymph, K; Adult, L. Type of Use: Direct spray or dust, M; Residue, N; Systemic, O; Fumigant, P. Method of Application: Dust, R; Spray, S; Aerosol, T. Pharmacology: Chronic, C; Acute, A. Order of Hazard: I, High; II, Moderate; III, Low.

TABLE 5-8. FUMIGANTS

Compound	Formula	M.P. (°C)	B.P. (°C)	V.P. at 25°C (mm Hg)	Specific gravity		Limit of inflammability in Air		Use	Ref.
					Liquid	Gas (air 1)	Lower (vol. %)	Upper (vol. %)		
Acrylonitrile (vinyl cyanide)	$\text{CH}_2=\text{CHCN}$	-83	77	107	0.80	1.83	3	17	Spot fumigation in mills	146, 147
Carbon dioxide	CO_2		-78		Solid	1.53	Noninflam-mable		Used to reduce fire hazards	148, 149
Carbon disulfide	CS_2	-112	46	361	1.26	2.63	1	50	Grain	150
Carbon tetrachloride	CCl_4	-23	77	114	1.6	5.31	Noninflam-mable		Grain	151, 152, 153
Chloropicrin	CCl_3NO_2	-64	112	24	1.65	5.7	Noninflam-mable		Grain, mills	154, 155
DD mixture	$\text{CHCl}=\text{CHCH}_2\text{Cl}$		108		1.22				Soil	156, 157, 158
Dichloro propylene (1,3-dichloro-propene)										
Propylene dichloride (1,2-propane)	$\text{CH}_3\text{CHClCH}_2\text{Cl}$		97		1.16		3.4	4.5	Grain; mixed with CCl_4 ; soil	
"Éthide" (1,1-dichloro-1-nitroethane)	$\text{CH}_3\text{CCl}_2\text{NO}_2$		124		1.40				Farm grain	159
Ethyl formate	HCOOC_2H_5		54		0.91		3	16	Packaged foods	160
Ethylene dibromide (1,2-dibromo-ethane)	$\text{CH}_2\text{BrCH}_2\text{Br}$	10	132	12	2.17		Noninflam-mable		Grain, soil	161, 162

Ethylene dichloride (1,2-dichloroethane)	$\text{CH}_2\text{ClCH}_2\text{Cl}$	-35	84	80	1.26	3.5	6	16	Grain, mills mixed with CCl_4	153, 162
Ethylene oxide	$(\text{CH}_2)_2\text{O}$	-111	11	>760	0.89	1.5	3	80	Vault (vac. and atms.) with CO_2	163, 164
Hexachloroethane	CCl_3CCl_3	Subl. 187			Solid 2.09				Clothes moths, soil	165
Hexachloropropene	$\text{CCl}_3\text{CCl}=\text{CCl}_2$	<0	203	0.3	1.75				Mills	166
s-Heptachloropropane	$\text{CCl}_3\text{CHClCCl}_3$		240	0.09					Mills	166
Hydrocyanic acid	HCN	-14	26	739	0.70	0.94	6	40	Mills, citrus trees, green-houses	167, 168
Methyl bromide	CH_3Br	-98	5	1824	1.73	3.27	13.5	14.5	Mills, warehouses, vaults	169
Methyl formate	HCOOCH_3		32		0.98		5	23	Vaults mixed with CO_2	170
Naphthalene	C_{10}H_8	80	218	0.1	Solid 1.15	4.41			Clothes moths	171, 172
Sulfur dioxide	SO_2	-73	-10	24° 2809		1.43	Noninflammable			173, 174
Tetrachloroethane	$\text{CHCl}_2\text{CHCl}_2$		146		1.60	5.8			Greenhouse soil	175
Trichloroethylene	$\text{CHCl}=\text{CCl}_2$	-73	87	73	1.45		Noninflammable		Grain	176

Poisoned baits have been used to a large extent in controlling many insect pests. Protein baits are being used with sprays in tests in Hawaii, Steiner¹⁷⁷. A study of these protein baits has been reported by Gow¹⁷⁸. Efforts have been made to incorporate in these baits some attractive element. As a rule, the most successful materials have been selected on the basis of representing a potential food source, although some efforts have been directed toward the use of sex specific lures. The latter is represented by the work of Steiner¹⁷⁹, using methyl eugenol.

Perhaps the greatest difficulty encountered in the use of either attractants or repellents is the lack of sufficient knowledge and understanding of the specific responses of insects to such stimuli or the mechanisms, either physical or biochemical, by which the insects react to these stimuli.

The use of repellents for insect control is largely restricted to those insects attacking man and animals. In general, repellents may act in two ways, as tactile repellents or as space repellents. In either case it is desirable to prevent the insect from feeding on the host or acting as a continuous annoyance to the host. In considering the use of repellents, host tolerance is of paramount importance since the compound will be applied directly to the surface of the host or in some cases, to the clothing to be worn by man.

The compounds listed in Table 5-9 by no means represent the entire range of materials available for such use^{191, 192}. As is indicated in this table, such compounds are intended for rather specific uses and represent a second line of chemical defense against insect attacks. The use of repellents as a means of preventing insect attack on crops and stored commodities is the subject of considerable research. Some compounds, i.e., pyrethrins and piperonyl butoxide combinations are not only toxic but appear to exert a repellent effect.

Fungicides

The term fungicide is used in a broad sense, not being restricted solely to those organisms properly classified as fungi³. Fungicides are employed for two broad purposes: to eradicate the fungi by direct action once they have become established on the host plant, or as a protective measure to prevent the fungi from becoming established. Various compounds may be effective for both purposes, the time and method of application determining the effect produced.

There appears to be rather general agreement concerning the first generally successful application of a chemical to combat fungi attacking a crop. Professor P. M. A. Millardet, of the University of Bordeaux, is credited with the introduction in 1885 of the use of mixtures of lime and copper sulfate to combat downy mildew of grapes. This mixture, known as Bordeaux mixture, has been a standard fungicidal treatment for years. The chemistry of Bordeaux mixtures is rather complex. A standard formula in

rather widespread use is 4-4-50, consisting of 4 pounds of copper sulfate and 4 pounds of hydrated lime made to 50 gallons of spray with water. As the use of Bordeaux mixture was extended, certain disadvantages became obvious, i.e., phytotoxicity, etc. The use of lime-sulfur, a mixture of calcium polysulfides formed by boiling sulfur and lime in water, was introduced around 1905. This was followed by the introduction of self boiled lime-sulfur formed by the addition of sulfur to stone lime slaking in water. These three mixtures were the standard fungicidal treatments for many years. Numerous inorganic and organic fungicidal compounds have been introduced over the years. As newer compounds have been developed, their application has become more specialized and the use of fungicides has been extended to provide more general protection or control. Considerable attention is being given to the use of antibiotics as fungicides. Streptomycin and terramycin have been explored as systemics and appear to afford considerable protection.

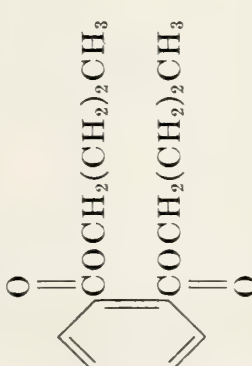
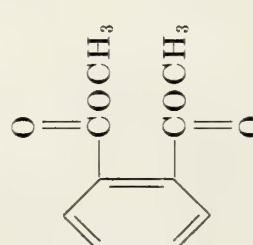
Fungicides are employed not only in the production of agricultural commodities, but also for their subsequent protection and the protection of other items of commerce from damage by fungi. Their uses range from the control of downy mildew of grapes to the prevention of fungus attacks on electrical insulation and optical devices.

In the application of fungicides in agricultural enterprises several methods are employed. They are applied as sprays or dusts to the plants in various stages of growth. Applications are made on the foliage, during the dormant season or as seed or soil treatments. In common with the other pesticides, some of the fungicides may have a systemic action. The advantages of such action are obvious. Progress in the field of plant chemotherapy or the use of systemics has been reviewed by Dimond¹⁹³. The future of fungicides and general research problems are discussed by Mc-New¹⁹⁴.

Inorganic Fungicides. Only a very limited number of inorganic fungicides are listed in Table 5-10. The compounds listed represent some of the commonly used copper, mercury and sulfur compounds. Most of these compounds are potentially phytotoxic. This is particularly true of the copper compounds. Soluble copper compounds are more effective than the insoluble copper compounds insofar as direct action on established fungi is concerned. Bordeaux mixture is a classical representative of these compounds. The undesirable effects of Bordeaux mixture, from both the copper and the lime, has lead to the use of fixed or insoluble copper compounds such as copper oxychloride. Copper zinc chromate, also known as Crag Fungicide 658, is particularly effective against diseases of tomatoes, cucurbits and peanuts. This is essentially a zinc chromate compound with a proportion of the zinc replaced by the copper.

The mercury chlorides are particularly hazardous materials. Mercuric

TABLE 5-9. REPELLENTS

Name	Formula	Insects affected	Method of application	Ref.
Dibutyl adipate	$\begin{array}{c} \text{O} & \text{O} \\ \parallel & \parallel \\ \text{C}_4\text{H}_9\text{OCC}_4\text{H}_8\text{COC}_4\text{H}_9 \end{array}$	Ticks	Impregnation of clothing	180
Dibutyl phthalate		Chiggers	Impregnated clothing	181, 182
Dimethyl phthalate		Mosquitoes, chiggers	Impregnated clothing, direct to skin	183, 184, 185
Ethylhexanediol (Rutgers 612)	$\begin{array}{c} \text{CH}_3\text{CH}_2\text{CHCH}(\text{CH}_2)_2\text{CH}_3 \\ | \quad \quad \quad | \\ \text{HCH} \quad \quad \text{O} \\ \quad \quad \quad | \quad \quad | \\ \quad \quad \quad \text{O} \quad \quad \text{H} \\ \quad \quad \quad | \quad \quad | \\ \quad \quad \quad \text{H} \quad \quad \text{H} \end{array}$	Mosquitoes	Impregnated clothing, direct to skin	186

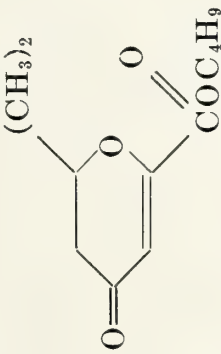

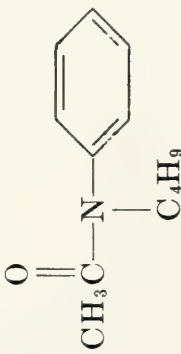
Indalone		Mosquitoes, ticks	Impregnated clothing	187
Benzylbenzoate		Fleas, chiggers	Impregnated clothing	188
N-Butylacetanilide		Ticks, fleas	Impregnated clothing	189
Crag fly repellent	Butoxy polypropylene glycols	Stable flies, house flies, horn flies, horse flies, etc.	Directly on animal	190

TABLE 5-10. INORGANIC FUNGICIDES

Name	Formula	Method of application	Type of action	Ref.
Bordeaux mixture.	$\text{CuSO}_4 + \text{Ca}(\text{OH})_2$	Foliage spray	Protectant	195, 196
Basic copper car-				
bonate.....	$\text{Cu}(\text{OH})_2\text{CuCO}_3$	Seed treatment	Protectant	197
Copper oxychloride	$3\text{Cu}(\text{OH})_2 \cdot \text{CuCl}_2$	Foliage spray	Protectant	198
Copper zinc chro-				
mate.....	?	Foliage spray	Eradicant	199
Lime sulfur.....	$\text{S} + \text{Ca}(\text{OH})_2$	Foliage spray	Protectant,	200
	Calcium polysulfides		eradicant	
Mercury chlorides.	HgCl_2	Soil treatments	Eradicant	201
	HgCl	Soil treatments		
Sulfur.....	S	Foliage dusts	Eradicant	202
		or sprays	protectant	

chloride is fast acting, but due to its high water solubility, of short duration. The mercurous compound gives longer protection. It is applied to the soil as either a dust or a spray.

Sulfur is one of the oldest pesticidal chemicals. The elemental form is applied either as a dust or spray. Lime sulfur is used primarily as a dormant spray. Applications of elemental sulfur are more effective as fungicides as the temperature is increased. Sulfur is also employed as an insecticide; the maximum insecticidal effect is obtained at temperatures ranging from 85 to 95°F. Sulfur is used to the largest extent on tree and bush fruits.

Certain of the arsenicals have also found use as fungicides. Both sodium and calcium arsenites have been used as fungicides for dormant applications. These compounds also find usefulness as insecticides and herbicides. Copper compounds and sulfur have been replaced to a large extent by the more recently developed synthetic organic fungicides.

Organic Fungicides. These compounds represent some of the more recently developed fungicidal materials²⁰³. Of those listed in Table 5-11, four are indicated as possessing systemic action. In addition to systemic type of action, the organic fungicides range from seed treatment to foliage sprays, acting either as eradicants or protectants.

PMAS, which is used in the control of turf fungicides, is also a potent herbicidal chemical. The use of Ceresan, another mercury compound, is primarily restricted to seed treatment. The toxicity of Ceresan to higher animals is a serious hazard. The other fungicidal compounds are not without some toxicity or objectionable effect to higher animals, but not of a sufficient level to be classed with Ceresan.

The most interesting series of compounds in this table are the dithiocarbamates such as Ferbam and Ziram. Ferbam and Ziram appear to be the most closely related compounds. Ziram is used most commonly on

TABLE 5-11. ORGANIC FUNGICIDES

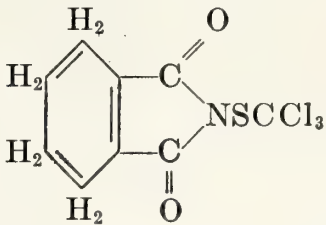
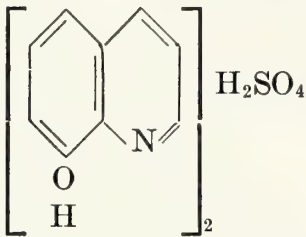
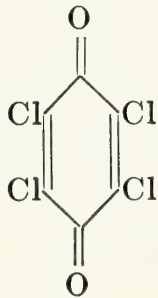
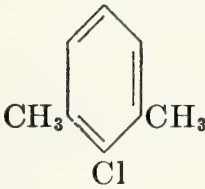
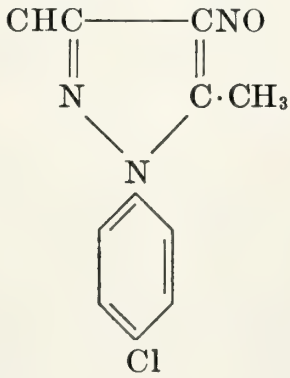
Name	Formula	Method of application	Type of action	Ref.
Captan		Foliage spray	Protectant	204
Ceresan	$(\text{CH}_3\text{OC}_2\text{H}_4\text{HgO})_2\text{Si}$	Seed treatment, dust	Eradicant, protectant	
Chinosol		Spray	Systemic	205, 206
Chloranil		Seed treatment	Protectant	207, 208
Chlorodimethylphenoxy ethanol	$\text{O}(\text{CH}_2)_2\text{OH}$ 	Soil spray	Systemic	209, 210
1-(p-chlorophenyl)-3,5-dimethyl nitrosopyrazole		Foliage spray	Protectant	211

TABLE 5-11—Continued

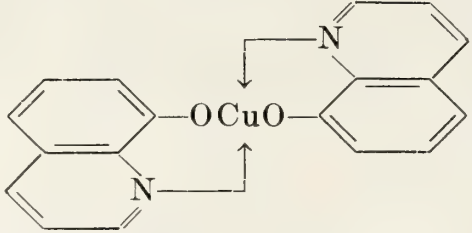
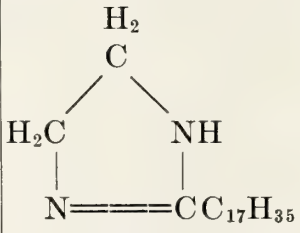
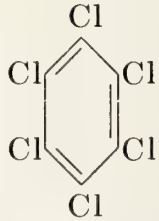
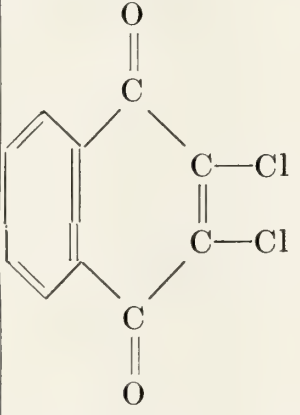
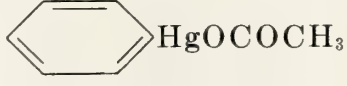
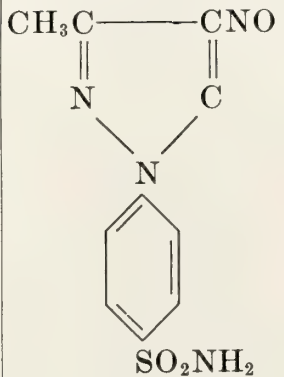
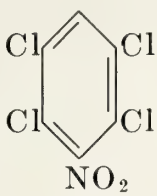
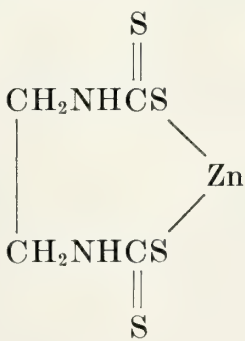
Name	Formula	Method of application	Type of action	Ref.
Copper 8-hydroxyquinolate		Foliage spray	Protectant	212
Heptadecylglyoxalidine		Foliage spray	Protectant	213
Hexachlorobenzene		Seed treatment, dust	Protectant	214
Phygon		Seed treatment, foliage spray	Protectant	215, 216
PMAS		Turf spray	Eradicant	217
1-(<i>p</i> -sulfamyl phenyl)-3,5-dimethyl-4-nitrosopyrazole		Seed treatment	Systemic	218, 219

TABLE 5-11—*Continued*

Name	Formula	Method of application	Type of action	Ref.
Technazine		Seed and soil dust	Eradicant	220
Ferbam	$\left[\begin{array}{c} \text{S} \\ || \\ (\text{CH}_3)_2\text{NCS} \end{array} \right]_3\text{Fe}$	Foliage spray	Protectant	221
Nabam	$\begin{array}{c} \text{S} \\ || \\ \text{CH}_2\text{NHCSNa} \\ | \\ \text{CH}_2\text{NHCSNa} \\ || \\ \text{S} \end{array}$	Foliage spray	Protectant, systemic	222
Thiram	$\begin{array}{c} \text{S} \quad \text{S} \\ || \quad || \\ (\text{CH}_3)_2\text{NCSCN}(\text{CH}_3)_2 \end{array}$	Foliage spray	Protectant	223, 224
Zineb		Foliage	Protectant	225
Ziram	$\left[\begin{array}{c} \text{S} \\ || \\ (\text{CH}_3)_2\text{NCS} \end{array} \right]_2\text{Zn}$	Foliage spray	Protectant	226

truck and vegetable crops, while Ferbam is used more extensively in orchards. The dithiocarbamates, with the exception of Nabam, possess little or no water solubility. The dithiocarbamates are generally not phytotoxic except for Nabam. This compound, however, can act as a systemic fungicide. Nabam is seldom used alone, but is mixed in the spray tank with zinc sulfate, resulting in a compound similar to Zineb. The phytotoxicity of Zineb is of importance only in the case of zinc sensitive plants.

Copper 8-hydroxyquinolate not only shows promise for disease control, but is also of value for the protection of fabrics. Chinosol has been indicated for the control of certain vascular wilts of crop plants. The two nitro-pyrazole compounds are closely related. The sulfamyl substitution in the benzene ring in place of the chlorine renders the compound of potential systemic value and appears to decrease the irritancy of the compound. The sulfamyl compound is also considerably more water soluble.

Although it might appear that water solubility would be an essential property for a systemic fungicide, the systemic properties of chlorodimethylphenoxy ethanol are apparently not dependent on water solubility. This situation also prevails for some of the systemic insecticides.

Technazine and hexachlorobenzene are both selective fungicides. Both are used as dusts for seed treatment. There is no evidence of a toxicity hazard to higher animals from Technazine. Both compounds are practically insoluble in water.

Herbicides

Weeds have undoubtedly been a problem for man ever since he took up agricultural pursuits. As more and more land areas have been taken over by man for his various uses, the elimination or reduction of unwanted vegetation, or weeds, has become a more costly problem. Chemicals have been used as a supplement to cultural practices in combatting weeds for centuries. The earlier materials may be compared with insecticides in that little was known of their action except their effectiveness. Salt and industrial by-products were early employed to control weeds in restricted areas. Herbicides are used to prevent the establishment of weeds or to reduce or eliminate weed populations after they have become established.

Since it is difficult to be extremely selective in the application of chemicals to an area, the use of herbicidal chemicals received a major stimulus in the discovery, around 1896, of the selective action of certain copper salts on broadleaved weeds. The earlier materials employed were sulfuric acid, iron sulfate and copper nitrate. Calcium cyanamide and sodium arsenite have also been employed extensively in weed control. Oils are very versatile, finding use as pesticidal solvents and possessing a pesticidal value themselves. The herbicidal uses of oils have been reviewed by Crafts²²⁷. The development of 2,4-D (2,4-dichlorophenoxyacetic acid) and other hormone-like compounds possessing considerable selectivity provided a new outlook on the use of herbicidal compounds.

The herbicidal properties of 2,4-D were discovered during World War II and by 1950 over 17 million pounds were consumed. This value had increased to over 25 million pounds by 1952. Over seven new herbicidal chemicals have been introduced commercially since 1944. The search for

new and more useful herbicidal chemicals will need to be expanded to keep pace with increasing demands for agricultural production.





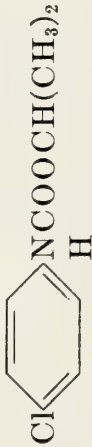


Herbicidal chemicals have been grouped by Robbins *et al.*²²⁸ into two major categories, selective herbicides and nonselective herbicides. Each of these categories are further subdivided into other classifications, the major ones depending on the route of application, i.e., foliage or root applications. The degree of selectivity of a herbicide is dependent on many factors. These factors are related to the amount and methods of application and the environmental conditions at the time of application as well as the potential biochemical specificity of the compounds.

Certain of the selective and nonselective herbicides may be translocated following application. The advantage in this type of action is obvious, since the toxicant will be transported to other regions of the plant where its lethal action may take place. Among the nonselective herbicidal chemicals will be found some compounds that are also employed as insecticides,

TABLE 5-12. INORGANIC HERBICIDES

Name	Formula	Selectivity	Type of application	Type of action	Ref.
Ammonium sulfamate...	$\text{NH}_4\text{SO}_3\text{NH}_2$	Nonselective	Foliage	Contact, translocated	230, 231
Ammonium thiocyanate	NH_4SCN	Nonselective	Foliage and root	Contact, translocated	232, 233
Arsenic tri-oxide.....	As_2O_3	Nonselective	Foliage and root	Contact, translocated	234
Carbon disulfide.....	CS_2	Nonselective	Roots	Contact	235, 236
Copper nitrate.....	$\text{Cu}(\text{NO}_3)_2$	Selective	Foliage	Contact	237, 238
Copper sulfate	CuSO_4	Selective	Foliage	Contact	
Cyanamide...	$\text{Ca}(\text{CN})_2$	Selective	Foliage, soil	Contact (seeds)	239, 240
Ferrous sulfate.....	FeSO_4	Selective	Foliage	Contact	241
Kainite.....	$\text{MgSO}_4 \cdot \text{KCl}$	Selective	Foliage	Contact	
Potassium cyanate....	KOCN	Selective	Foliage	Contact	242
Sodium arsenite.....	Na_3AsO_3 or/ and NaAsO_2	Nonselective	Foliage, roots	Contact, translocated	243, 244
Sodium chlorate.....	NaClO_3	Nonselective	Foliage, roots	Contact, translocated	244, 245
Sulfuric acid.	H_2SO_4	Selective	Foliage	Contact	246, 247

TABLE 5-13. ORGANIC HERBICIDES

Name	Formula	Selectivity	Type of application	Type of action	Ref.
2,4-D		Selective	Foliage, roots	Translocated	249, 250
2,4,5-T		Selective	Foliage	Translocated	251
MCPA		Selective	Foliage	Translocated	252, 253
IPC		Selective	Roots	Contact	254, 255
Cl IPC		Selective	Foliage, roots	Contact	248, 256, 257
PMAS		Selective	Foliage	Contact	258, 259
TCA		Selective	Foliage, roots	Contact	260


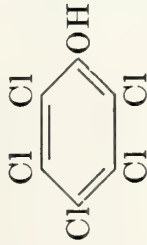
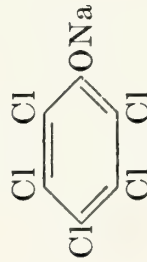


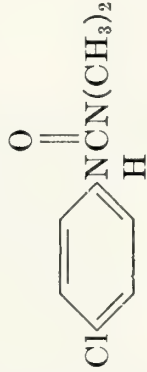
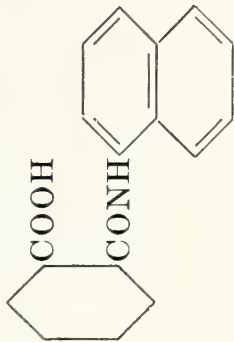
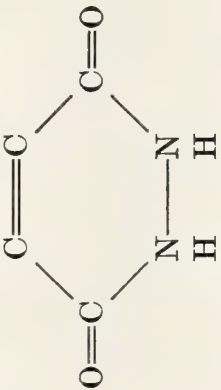
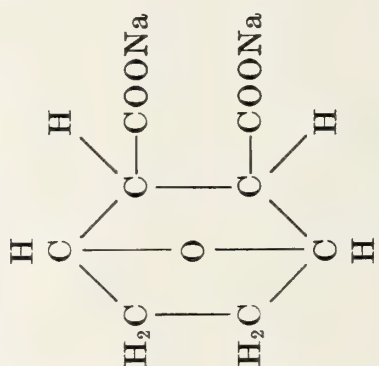
Dinitrophenols		Selective	Foliage	Contact	261
Pentachlorophenol		Nonselective	Foliage	Contact	262
Sodium pentachlorophenate		Selective	Roots	Contact	
EH No. 1, Crag No. 1		Selective	Roots	Contact	263, 264
Dichloral urea		Selective	Roots	Contact	265
CMU		Selective	Roots	Contact	266, 267
Naphthylphthalamic acid		Selective	Roots	Contact	268, 269

TABLE 5-13—Continued

Name	Formula	Selectivity	Type of application	Type of action	Ref.
Maleic_hydrazide		Selective	Foliage	Contact, translocated	270, 271, 272
Endothal		Selective	Foliage	Contact	273, 274

the effects they produce being largely controlled by the amounts and routes of application. The specific problem of herbicidal formulations has recently been discussed by Kelly²²⁹. Several of the more recently introduced materials, used at sublethal concentrations, manifest other changes in plant growth which may be advantageous. Action as growth regulators is treated in other chapters.

Inorganic Herbicides. The list of inorganic herbicides in Table 5-12 represents a wide range of compounds having diverse applications. These compounds represent some of the earlier used herbicidal materials. Several of these compounds have dual uses, being effective as insecticides and at higher rates of application exhibiting herbicidal action. This is particularly true of the arsenicals. Carbon bisulfide which is used for soil application in weed control is also toxic to soil inhabiting insects. Because of its inflammability, its uses are seriously limited.

Soil types may have a decided effect on the action of herbicides applied in soil treatments. As with other pesticidal applications, a variety of factors must be taken into consideration. Aqueous solutions of many of the inorganic herbicides derive their selectivity by selective wetting of the foliage surface. This is particularly true of iron and copper sulfates, sulfuric acid and potassium cyanate. The nonselective compounds such as sodium arsenite have been used in areas where elimination of all vegetation is desirable, i.e., railroad right of ways, fence lines, etc. The factor of mammalian toxicity indicates the uses of a less toxic compound where toxicity to higher animals must be considered.

Organic Herbicides. The organic compounds listed in Table 5-13 tend to be more selective in their herbicidal action than the inorganic compounds. Much of the selectivity of these compounds is of a biochemical nature. Biochemical selectivity combined with other selective characteristics makes these compounds particularly useful. The total action of many of these compounds is dependent upon the dosage rates.

The development of 2,4-D as a herbicide may be compared with the discovery of DDT. Many new organic herbicidal compounds have been developed since its introduction. The close relationship in the structure of many of these compounds is evident in Table 5-13. In addition to possible changes in biochemical specificity, the solubility of the compounds in various solvents plays an important part in their action. Various salts and esters of 2,4-D compounds are relatively nontoxic to the higher animals. Drift of such compounds from treated areas during application may pose serious difficulties, particularly when adjacent cropped areas are in sensitive crops.

IPC, isopropyl phenylcarbamate, is not effective as a foliage application, exerting its action only after contacting the roots. The chlorinated form

of this compound, Cl IPC, is water soluble and appears to be effective as a foliage application. PMAS, phenyl mercuric acetate, is a potentially hazardous compound. Under certain conditions of use it exhibits fungicidal action.

The dinitrophenols and pentachlorophenols are used as herbicides and, with other rates and methods of application, are used as insecticides. The soil fumigants such as methyl bromide and chloropicrin are also good examples of multiple use pesticidal compounds.

As is true with insecticides and fungicides, it is impractical to give specific details as to the range of use of each herbicidal chemical. Each has specific advantages and limitations which must be taken into account²⁴⁸. The mode of action of these compounds is complex and in general requires exploration of the biochemistry of the pest under consideration before progress can be made in specific details of action.

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Current Literature

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Bibliography of Agriculture



6. GROWTH REGULANTS, THEIR NATURE AND ACTION

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A growth regulant may be defined as an organic compound which, usually in low concentrations, will modify the rate or coordination of growth in plants. The chemical may operate by depressing or accelerating processes that regulate the three essential stages of growth: cell division, cell elongation, and cell differentiation.

Many of the early studies on natural regulants have been concerned with cell elongation in etiolated isolated plant parts. The growth observed under these conditions is the result of water absorption. More recently, workers have become interested in a variety of responses to chemical stimuli and many of these have found practical applications. Initiation of roots, control of bud growth, effects on flowering responses, hastening or retardation of ripening of fruit, control of abscission, and selective herbicidal action by synthetic growth regulants have all received much attention.

Much more progress has been made in the field of synthetic growth regulants than in the development of information on the nature and action of natural regulants. Knowledge of the natural growth regulants is confined mainly to 3-indoleacetic acid and related indole compounds. With the increasing use of paper chromatography it is likely that rapid advances will be made in the identification of natural regulants concerned with many plant processes affecting growth in its various aspects.

Historical

Botanists and plant physiologists have been interested for a long time in the factors responsible for correlating the growth activities of different plant organs. Many have speculated that chemical substances similar to hormones in animals may be important in affecting the development of

various organs. Darwin²⁰, working with *Phalaris canariensis*, showed that the coleoptile is particularly sensitive to light stimulus and that when it is illuminated from one side it bends toward the light. He also found that the tip was important in connection with this response and that when it was removed or covered over with a light-proof material no response occurred on exposure to light. Later it was shown by Boysen-Jensen¹⁴ (1911), working with the oat coleoptile, that the stimulus from the tip could pass through nonliving material such as gelatin. Paál⁸⁹ (1919) found that when the tip was removed it could influence growth without the presence of light. The reaction of the coleoptile to light therefore seemed to be regulated by a redistribution of some chemical formed at the tip, the larger amounts going to the darker side where the most growth took place.

The time was now ripe for the work of F. W. Went who used agar blocks for the collection of the substances formed by the coleoptile tips. He developed the quantitative method for determining the amount of growth substance known as the Went *Avena* test. In this method, the details of which are described fully in a number of readily available references^{3, 115}, the degree of curvature is measured when agar blocks containing growth substances are placed asymmetrically on decapitated coleoptiles. The degree of curvature resulting, when the test is carried out under the prescribed conditions, is proportional to the concentration of growth substance within the limits of approximately 10 to 50 micrograms of indoleacetic acid per liter.

The development of this test method served as a tremendous impetus to the investigation of growth substances. It aided most importantly in studies on the isolations of naturally-occurring substances by making possible determinations of the effectiveness of procedures for concentrating the active materials. A large number of other test methods have been developed since that time which have proved valuable for various purposes. This has followed since growth regulant chemicals have been found to be useful for a large number of applications. For these different applications specific tests are naturally of importance. An advantage of the *Avena* curvature test has been its extreme sensitivity as compared to that usually possible with strictly chemical tests. With the *Avena* test it is possible to determine 10^{-2} micrograms of indoleacetic acid quantitatively.

The Naturally-Occurring Growth Regulants

Auxin a and b. The determination of the identity of the naturally-occurring growth substances has been beset with many difficulties. It was apparent early in these investigations that the oat coleoptile, the test object with which most workers were concerned at that time, contains too small quantities of the active material to be a reasonable source for isolation

studies. An *Avena* tip contains about $1/50,000,000$ of a milligram of growth substance³⁷. It was found, however, that urine has considerable activity in the *Avena* test and accordingly Kögl, Haagen-Smit, and Erxleben⁶⁰ used this as starting material. A fairly complex isolation procedure, starting with lots of urine of 100 liters or more, yielded about 100 mg of crystalline material. This had an activity of about 50×10^9 *Avena* units per gram. An *Avena* unit is defined as the quantity of growth substance required to give 10° of curvature in the *Avena* test under the prescribed conditions. This corresponds to only $1/50,000$ of a microgram or 36×10^9 molecules per unit. Two active crystalline products were obtained, one with a melting point of 196° considered to be the active acid and one with a melting point of 172 to 173° , an active lactone of the former. The term auxin, from the Greek, *αὔξω* meaning to induce growth, was suggested as a designation for the material isolated.

Isolation from plant material was of course necessary to be sure that the material from urine had any function as a plant growth regulant. Accordingly Kögl, Erxleben, and Haagen-Smit⁵⁹ investigated a number of possible plant preparations as likely material to use for the isolation of active material. After a study of the growth regulant content of various oils they found a sample of corn oil which was especially rich in a substance or substances active in the *Avena* test. Indicated content was 600 to 700 micrograms per kg. Starting with 16 kg of oil two crystalline products were obtained, one identical with that obtained from urine and now called auxin a, and a second new material designated as auxin b. Only 15 mg of the crude crystalline preparation of each was obtained from the 16 kg of oil. In an attempt to repeat the isolation starting with a 32-kg portion of the oil it was found that it had become inactive in the meantime and another source of active corn oil could not be located. An examination of 22 varieties of barley and a study of their auxin content after germination for a number of days resulted in finding a variety containing 420 micrograms per kg. Some of the varieties examined contained no detectable auxin. Isolation from 160 kg of the most active source yielded 238 mg of crystalline auxin b, and 7 mg of auxin a.

In a later publication, Kögl, Haagen-Smit, and Erxleben⁶¹ reported that it was often not possible to obtain active crystalline material from various batches of mixed urine. The auxin content of urine from various individuals varied as much as four- to fivefold. In an effort to improve the isolation procedure these authors obtained an entirely different active product which was shown to be 3-indoleacetic acid. It had about the same order of activity as auxin a and auxin b. The authors were convinced, however, that 3-indoleacetic acid was not a plant growth substance and that its presence in the urine was the result of the breakdown of tryptophane by the action of micro-

organisms. The name heteroauxin or other auxin was suggested for the indole compound and this persisted for a long time. The name is being abandoned since it is now believed that 3-indoleacetic acid is indeed important as a natural plant growth regulant and the role for auxin a or b is becoming increasingly doubtful.

Kögl and Erxleben⁵⁸ studied the chemical properties of auxins a and b and although they had only several hundred milligrams available for study they were able to suggest a formula for both materials. The correctness of the formula has not been verified by synthesis. Synthesis offers a considerable problem because of the number of asymmetric carbon atoms involved. In the meantime verification of the isolations has not been forthcoming from other laboratories nor from the same laboratory. Haagen-Smit, Leech, and Bergren³⁹ reported making a search for plant material high in auxin similar to that previously used by Kögl *et al.*⁵⁹ but without success. They obtained a small amount of inactive material from corn meal which is described as pseudo-auxin a, but the major part of the auxin activity was recovered as 3-indoleacetic acid.

Since confirmation of the role of auxins a and b has not been available in the 20 years since the original publications, decreasing emphasis is being placed on these materials. Gordon³² states that increasing importance is being ascribed to 3-indoleacetic acid as the major auxin in higher plants and "several researchers privately expressed doubt as to the existence of auxin a and b". Recently Wieland, DeRopp, and Avenier¹¹⁶ have repeated the isolation procedure of Kögl, Haagen-Smit, and Erxleben⁶⁰ with two 40-liter samples of urine. The auxin activity was followed by the split coleoptile test of Thimann and Schneider¹⁰⁸ which will detect 0.01 γ per liter of 3-indoleacetic acid. Only 3-indoleacetic acid and its methyl ester, the latter arising as a result of the isolation procedure, were obtained. The authors conclude that neither of the two 40-liter samples contained any auxin except indoleacetic acid.

3-Indoleacetic Acid and Other Indole Compounds. As indicated above, the growth regulating activity of 3-indoleacetic acid was first discovered by Kögl, Haagen-Smit, and Erxleben⁶¹ as a result of their isolation of this substance from urine while looking for auxin a. Indoleacetic acid had been isolated previously from urine by Herter⁴⁶ and its presence indicated but not proved in *Celtis reticulosa*⁴⁷. Any significance of indoleacetic acid as a growth-regulating substance was at first discounted since auxins a and b were presumed to be *the* auxins even though indoleacetic acid had comparable activity, quantitatively in the *Avena* test. Indoleacetic acid was also isolated from yeast by Kögl and Kostermans⁶² and from cultures of *Rhizopus sinensis* by Thimann¹⁰⁵. Indoleacetic acid was at first considered to be associated only with the lower organisms. Further studies of growth

regulating activities in higher plants led to its isolation from this source also.

Haagen-Smit, Leech, and Bergren³⁹ working with corn meal in 1942 obtained crystalline indoleacetic acid as indicated by melting point and mixed melting point determinations. They also isolated some crystals which were thought to be pseudo-auxin a. Later, Berger and Avery⁸ (1944), who were interested in an auxin precursor in corn, obtained crystalline 3-indoleacetic acid which was identified by its melting point and mixed melting point and by its infrared spectrum. Haagen-Smit, Dandliker, Wittwer, and Murneek³⁸ (1946) also reported the isolation of crystalline 3-indoleacetic acid from corn kernels in the milk stage. On the basis of the *Avena* test they estimated that 100 kg of the kernels contained 1.48 g of the acid. Their isolation procedure resulted in a yield of 9 per cent of this amount in pure crystalline form. The acid was characterized by its melting point, mixed melting point, and analysis for C, H, and N.

In 1951 Redemann, Wittwer, and Sell⁹² isolated the fruit setting factor from an ethanol extract of immature corn kernels. This proved to be the ethyl ester of 3-indoleacetic acid. It was obtained as the 1,3,5-trinitrobenzene adjunct. It was 100 times as active as the acid in inducing fruit set in the tomato. All the isolations of 3-indoleacetic acid have involved seeds and no isolation has been made from actively growing plant material. Jones, Henbest, Smith, and Bentley⁵³ have reported the isolation of 3-indoleacetoneitrile from cabbage leaves. It had been found that various members of the Cruciferae, such as radish, cauliflower, swede, and turnip, gave extracts in which substantially all of the growth substance activity was in the neutral fraction. The neutral material showed activity in the *Avena* straight growth test several times greater than 3-indoleacetic acid. Extraction of 500 kg of cabbage gave 915 mg of the active material. It was identified as 3-indoleacetoneitrile by microanalysis, infrared spectra, alkaline hydrolysis to 3-indoleacetic acid and reduction to tryptamine with lithium aluminum hydride. Tests indicated that its activity is not the result of conversion to the acid.

Larsen⁶⁵⁻⁶⁹ has also been interested in a neutral substance with growth-regulating activity. This is thought to be 3-indoleacetaldehyde and its activity is presumed to be the result of its ready conversion to 3-indoleacetic acid¹⁵.

With the greater use of paper partition chromatography emphasis is being placed on the more definite characterization of the active substances in plants^{6, 52, 72, 73}. Bolle-Jones has reported the presence of 3-indoleacetic acid in the laminae of *Hevea brasiliensis*¹¹. Evidence is accumulating that indole compounds other than 3-indoleacetic acid may be widespread in their occurrence. Stowe and Thimann¹⁰⁰ have found 3-indolepyruvic acid

in maize endosperm and suggest that unidentified substances reported by Bennet-Clark and Kefford⁵, Lexander⁷⁰, and Terpstra¹⁰⁴ are also probably indolepyruvic acid. Vlitos and Meudt¹¹⁴ found what is presumably 3-indolepyruvic acid in leaves of the Biloxi and Lincoln soybeans and in leaves of Maryland Mammoth tobacco. Larger quantities were detected when plants were grown under photoinductive daylengths. Fischer²⁵ has used both paper chromatography and paper electrophoresis in studying the indole compounds in plants and has shown the presence of 3-indoleglycolic acid, 3-indolealdehyde, and 3-methylindole in plants in addition to others previously reported.

Naturally-Occurring Bound Auxins. In addition to the natural growth-regulating substances which can be obtained from various plant tissues by simple extractions, further treatment in various ways will release more active material. The activity obtained in this way has usually been referred to as being present in bound form. In some instances compounds closely related to 3-indoleacetic acid are involved which by simple hydrolysis or oxidation are converted to the former. In other examples protein hydrolysis, either enzymic or by alkali, yields further material which is active in the *Avena* test. Considerable emphasis has thus been placed on protein bound auxin.

Much work has been done by Avery and co-workers^{4, 9}, Hatcher⁴⁵, and Haagen-Smit *et al.*³⁹ on the auxin precursor in the seeds of corn, wheat, and rye. By far the larger part of the activity, as measured by the *Avena* test, is released only after mild alkaline hydrolysis. In view of the isolation of ethyl 3-indoleacetate from corn by Redemann, Wittwer, and Sell⁹², and the fact that the ester is not as active in the *Avena* test as the acid⁶³, it is likely that a good part of the so-called bound auxin in these seeds is the ester of 3-indoleacetic acid.

Stewart *et al.*^{98, 99} have investigated a growth inhibitor present in radish. Its chemical nature is not known. It has approximately the same molecular weight as 3-indoleacetic acid and readily yields the latter on oxidation.

Skoog and Thimann⁹⁶ found that an increase of auxin could be obtained from *Lemna* tissue by the addition of proteolytic enzymes. Since then much work has been done on the hypothesis that 3-indoleacetic acid occurs bound to proteins in plant tissue. Wildman and Gordon¹¹⁸ studied the release of a substance active in the *Avena* test on enzymic hydrolysis of proteins isolated from spinach leaves. It is suggested by Bonner¹² that the data of Wildman indicate that one to a few molecules of indoleacetic acid are associated with each protein molecule. He also points out that the methods involved in the freeing of indoleacetic acid from proteins probably bring about in addition some conversion of protein bound tryptophane to 3-indoleacetic acid. Gordon and Wildman³⁵ found that tryptophane when heated in dis-

tilled water and especially with 0.00025 to 0.25*N* sodium hydroxide readily yielded a substance active in the *Avena* test. Casein also gave large amounts of active material when heated with alkali. The authors stress that results obtained by the alkaline hydrolysis of plant products be reviewed in the light of these observations on the ready auxin formation from tryptophane under similar conditions. Similarly Schocken⁹⁴ found that chymotrypsin, fibrin, β -lactoglobulin, ovalbumin, serum albumin and other proteins all yielded an auxin believed to be indoleacetic acid when refluxed at 100°C in 0.1*N* NaOH. The yields of auxin were roughly proportional to the tryptophane content of the proteins. The author suggests that "this type of so-called 'bound auxin' would, therefore, appear to be associated neither with any special enzymatic activity of the protein, nor specifically with plant growth or plants." Recently Yamaki and Makamura¹²⁰ have also indicated their belief that indoleacetic acid which occurs from the hydrolysis of proteins is the result of conversion of tryptophane.

Ethylene. Another naturally-occurring substance with growth regulant activity is the unsaturated hydrocarbon, ethylene. The physiological effects of ethylene in plants were known for many years before it was discovered to be a natural product of plant metabolism. Neljubow^{83, 84} (1901, 1911) on investigating the reason for the abnormal growth of pea seedlings in laboratory air found that the effect could be duplicated by low concentrations of ethylene and to a lesser extent by acetylene. Effects of ethylene in producing epinasty (downward curvature of petioles) and other physiological responses were also observed early by Harvey⁴⁴, Doubt²³, Knight and Crocker⁵⁶, and Knight, Rose, and Crocker⁵⁷. In 1932 Crocker, Zimmerman, and Hitchcock¹⁹ tested the effectiveness of ethylene in producing epinasty in 202 species of plants. Epinasty was induced in 89 species and not in 113. A total of 38 gases was tested and only ethylene, acetylene, propylene, carbon monoxide, and butylene were effective. The relative concentrations required to produce the same effect were 1, 500, 500, 5000, and 500,000 respectively. In the meantime, ethylene had also been found by Denny²¹ to hasten the ripening of lemons at concentrations of about one ppm.

The discovery of ethylene as a natural product of plant metabolism started with the observation of Elmer²⁴ in 1932 that an emanation from apple fruits induced an abnormal development of potato sprouts. Subsequently Huelin⁵⁰ (1933) showed that similar effects were produced by ethylene. Denny and Miller²² found that many plant parts give off ethylene as indicated by epinastic responses. Finally Gane^{29, 30} isolated ethylene from the air surrounding apple fruit. Since that time additional chemical proofs of the emanation of ethylene from various plant sources have appeared^{43, 85, 86, 90}.

There is thus ample evidence that ethylene belongs to the natural

growth-regulating substances¹⁸. Some have excluded ethylene from the growth regulants as a result of restricting the definition as to what can properly be called a natural growth regulant.

In addition to its use in hastening the ripening of fruit, ethylene has had some commercial application to bring about flowering in the pineapple. It was discovered that smoke forced pineapple plants into flowering¹⁰⁹ and this was found to be due to presence of unsaturated hydrocarbons, principally ethylene⁹³. Acetylene was also found to be active and these unsaturated hydrocarbons found widespread use in the pineapple industry. At present their use has declined considerably as they are being replaced by naphthaleneacetic acid¹¹¹. Acetylene as such has not been shown to be a natural plant product but acetylene compounds in considerable variety have been isolated from several genera of Compositae and from fungi¹.

Tests for Growth Regulant Activity

As mentioned earlier the *Avena* curvature test was at first used for the detection and quantitative determination of active materials. As many workers became interested in chemicals with growth regulant activity other test methods were developed. Some of the chemicals in commercial use are inactive or of very low activity in the *Avena* test and therefore would not have been discovered if other test methods had not been used. Naturally if a desired activity is being sought a method measuring this activity directly is to be preferred.

Bonner¹² lists a total of 20 tests that have been used in growth regulant studies. These are divided into those measuring cell elongation, cell division, inhibition, and various miscellaneous tests including effects on flower initiation, ripening of fruit, water uptake, and closing of stomata. Various workers have devised tests which meet the requirements of their particular problems. Substances active in one test may be completely inactive in another so that in general the discovery of substances active in various responses is dependent upon appropriate methods for measuring the response in question.

Enzyme Systems Associated with the Natural-Growth Regulants

Additional evidence that 3-indoleacetic acid is one of the important natural-growth regulants is the presence of enzymes in many plant tissues associated with the metabolism of 3-indoleacetic acid. The ability of living plant material to form auxin from tryptophane has been shown for spinach, pineapple, pea, and tomato by Wildman, Ferri, and Bonner¹¹⁷, Gordon and Sánchez Nieva^{33, 34}, Galston²⁶, and Tsui¹¹⁰, respectively. The process is enzymatic and is inhibited by 10^{-2} or 10^{-3} *M* cyanide or sodium bisulfate with spinach leaves infiltrated with tryptophane. Cell-free extracts of

spinach leaves were also found capable of bringing about the conversion. The product formed has not been identified chemically but is presumed to be 3-indoleacetic acid. Among the intermediate compounds may be indolepyruvic acid and indoleacetaldehyde¹². The latter is converted to 3-indoleacetic acid by excised oat coleoptiles and by coleoptile juice⁶⁷.

Tang and Bonner^{101, 102} found that etiolated pea seedlings contain an enzyme which oxidizes 3-indoleacetic acid. Also found was a water-soluble thermostable factor which inhibited the action of the enzyme. The enzyme was also present in *Avena* and in roots, and in etiolated cabbage leaves, but not in green plants. Exposure to light diminished the content of inactivating enzyme. The indoleacetic acid oxidase was later shown to be a multiple enzyme system consisting of a light-activated flavoprotein which produces oxidase from an unknown substrate and a peroxidase which uses the peroxide in the oxidation of indoleacetic acid^{27, 28}. Andreae and Andreae² presented evidence that hydrogen peroxide is liberated during the oxidation of indoleacetic acid. The significance of this oxidase in helping to maintain the indoleacetic acid balance in growing plants is not yet entirely clear.

Synthetic Growth Regulants

As soon as it was found that 3-indoleacetic acid had growth regulant activity, investigations of related compounds got underway. Even before this Zimmerman, Crocker, and Hitchcock^{121, 122} had shown that ethylene, acetylene, propylene, and carbon monoxide caused rooting responses in 15 species of plants. Figure 6-1 shows the adventitious roots formed by African marigold during exposure to 0.2 per cent ethylene at two-day intervals, for a six-day period. Soon after it became known that 3-indoleacetic acid had growth regulant activity, Hitchcock⁴⁸ found that in addition indolepropionic, phenylacrylic, and phenylpropionic acids, dissolved in water, oil, or in lanolin and applied locally to intact plants, caused initiation of roots, epinasty of leaves, and bending and swelling of stems of several varieties of plants. Thus began a tremendous amount of activity in making and testing synthetic organic chemicals for theoretical studies and for possible practical use in agricultural practice. Possibly as many as 100,000 compounds have been tested for some kind of growth regulant activity.

A few months after the appearance of Hitchcock's paper⁴⁸, Zimmerman and Wilcoxon¹²⁵ (1935) added α - and β -naphthaleneacetic, acenaphthyl-(5)-acetic, indolebutyric, phenylacetic, fluoreneacetic, and anthraceneacetic acids, and α -naphthylacetonitrile to the list of active substances. The discovery of additional substances, once the structure of one occurring in nature was known, was therefore very rapid. The list above includes two, indolebutyric and α -naphthaleneacetic, acids that have had wide application.



Figure 6-1. Branch roots produced on adventitious roots of African marigold during exposure to 0.2 per cent ethylene at 2-day intervals for 16 days. (After Zimmerman and Hitchcock¹²²)

The number of substances active in modifying growth was greatly increased following the discovery of the effectiveness of β -naphthoxyacetic acid⁵¹ and the extensive studies of Zimmerman and Hitchcock, reported in 1942, on the growth regulant properties and selective action of the various substituted aryloxyacetic acids^{123, 124} and benzoic acids¹²⁴. The investigations on various derivatives of phenoxyacetic acid by Zimmerman and Hitchcock and by Slade, Templeman, and Sexton⁹⁷ led to the development of selective herbicides that are currently being used at the rate of 30 million pounds per annum in the United States.

Figure 6-2 shows some of the effects produced by 2,4-dichlorophenoxyacetic acid and related compounds as reported by Zimmerman and Hitchcock in 1942. The upper photograph shows effects of spraying with 2,4-D as evident after 24 hours and the lower picture shows the type of formative effects produced in the new growth.

Since 1942 there has been a rapid development in the practical use of growth regulants in agriculture. Additional new compounds have been discovered as well as new uses for some of the known compounds. In Table 6-1



Figure 6-2. (A) Plants sprayed with 2,4-dichlorophenoxyacetic acid, photographed after 24 hours. Left to Right: Control; sprayed with (2) 25 mg/l; (3) 50 mg/l; (4) 100 mg/l.

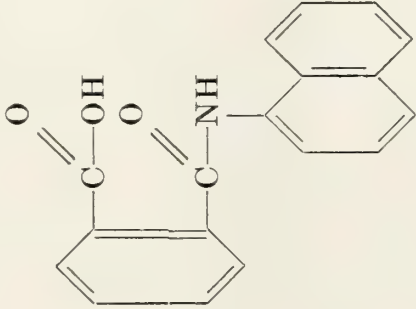
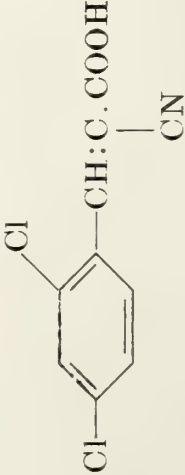
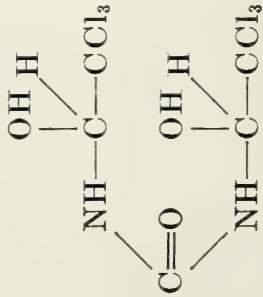
(B) Formative effects evident in new growth after treatment. Left to right: (1) Control; (2) sprayed with *p*-chlorophenoxyacetic acid, 100 mg/l. 19 days previously; (3) plants treated 15 days previously with *o*-chlorophenoxyacetic acid, 10 mg/l lanolin. (After Zimmemrman and Hitchcock¹²⁴).

are listed some of the chemicals in commercial use or under large-scale test for growth-regulant applications. Some of the chemicals used as herbicides are omitted since herbicides are being discussed in another chapter and also because some of the herbicides act in a manner different from that of a growth regulant.

Some of the synthetic growth-regulant chemicals act in extremely low concentration as does the naturally-occurring 3-indoleacetic acid. In fact, some of the chemicals rank among the most physiologically active substances known. Quantities of 2,4-dichlorophenoxyacetic acid of a pound or less per acre will control weeds. The use of an ounce of 1-naphthaleneacetic acid will induce flowering in an acre of pineapples and under especially

<div><div><div>CH₃</div><div><div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div>Cl</div></div><div><div><div>OCH₂COOH</div></div></div></div>	4-Chloro- <i>o</i> -tolylxyacetic acid, 4-Chloro-2-methylphen- oxyacetic acid	Retardation of growth through effects on me- tabolism, similar to 2,4-D	Slade, Templeman, and Sexton ⁹⁷
<div><div><div>Cl</div><div><div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div>Cl</div></div><div><div><div>OCH₂COOH</div></div></div></div>	2,4,5-Trichlorophenoxy- acetic acid, 2,4,5-T	Similar to 2,4-D but more effective on certain spe- cies, especially woody plants	Hamner and Tukey ⁴⁰
<div><div><div>Cl</div><div><div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div>Cl</div></div><div><div><div>OCH₂CH₂OSO₂ONa</div></div></div></div>	Sodium 2,4-dichlorophen- oxyethyl sulfate	Killing of germinating seeds	King and Lambrech ⁵⁵
<div><div><div>O</div><div><div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div></div><div></div><div></div><div></div><div></div><div></div></div></div></div><div><div><div>NHC—OCH(CH₃)₂</div></div></div></div>	Isopropyl <i>N</i> -phenylcarba- mate, IPC	Effect on germinating grass seeds	Templeman and Sex- ton ¹⁰³
<div><div><div>O</div><div><div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div></div><div></div><div></div><div></div><div></div><div></div></div></div></div><div><div><div>NHC—OCH(CH₃)₂</div></div></div><div><div><div></div><div></div><div></div><div></div><div></div><div>Cl</div></div></div></div>	Isopropyl <i>N</i> -(3-chloro- phenyl) carbamate, IPC	Toxic to germinating seeds Inhibition of sprouting of potato tubers	Witman and Newton ¹¹⁹ Martin and Schultz ⁷⁶
<div><div><div>O</div><div><div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div></div><div></div><div></div><div></div><div></div><div></div></div></div></div><div><div><div>NH</div><div><div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div>NH</div></div><div><div><div>HC</div><div><div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div>HC</div></div></div><div><div><div>C</div><div><div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div>C</div></div></div><div><div><div>O</div><div><div><div></div><div></div><div></div><div></div><div></div><div></div></div></div><div><div><div></div><div></div><div></div><div></div><div></div><div></div></div></div></div></div></div></div>	1,2-Dihydro-3,6-pyrida- zinedione, maleic hydra- zide	Inhibiting effect on plant growth Reduces sprouting of stored root crops	Schoene and Hoffmann ⁹⁵

TABLE 6-1—Continued

Formula	Name	Effect	Ref.
	<i>N</i> -1-naphthylphthalamine acid	Stimulation of fruit set, parthenocarp, formative effects on leaves	Hoffmann and Smith ⁴⁹
	α -Cyano- β -(2,4-dichlorophenyl) acrylic acid	Inhibitory on plant growth	Ligett ⁷¹
	Bis-(1-hydroxy-2,2,2-trichloroethyl) urea, di-chloral urea	Inhibitory to grasses	King ⁵⁴

favorable conditions a gram per acre may suffice. In this connection the work of Marth, Preston, and Mitchell⁷⁵ with the 1-piperidine carboxylate of (4-hydroxy-5-isopropyl-2-methylphenyl)trimethyl ammonium chloride is of special interest. When added to the soil in which bean plants were growing this chemical persisted apparently undiminished for a period of three years at the 10 and 100 lb per acre rate. The effect of the compound absorbed from the soil and translocated to the seed was still evident in the following two successive generations, but no longer apparent in the fourth generation. The effect on the plants was to produce shorter plants with darker green leaves and to delay flowering so that the plants with the highest dosage were still flowering when the controls had ceased and had mature pods. The persistence of the effect through the seed for several generations indicates this chemical must exert action at very low concentrations.

Relation Between Structure and Activity

As with all biological effects produced by chemicals there has been considerable interest in noting the relation between chemical configuration and activity. These studies have been handicapped in part by differences in test methods used by various workers, and some of the discussions have been confused by trying to reconcile results obtained by different methods. Actually, as pointed out by Veldstra¹¹², it is possible to study effects of structural variation for a variety of responses. Most of the work has been carried out in connection with effects on cell elongation. With this test as with others it is not possible to bring about direct exposure to primary active sites for the compounds being studied. Factors of penetrability, solubility, and instability of compounds being tested therefore complicate the picture. Furthermore, many substances which may stimulate at some concentrations will inhibit at higher concentrations. Even if tests are held within the area of stimulation, for example, curves representing the relation between dose and response may have different slopes for different compounds. When this happens the curves may cross each other so that the relative effectiveness of two compounds may be qualitatively different at some concentrations from that at other concentrations.

The above considerations account in part for the controversial nature of the papers on this subject. In spite of these shortcomings the studies have led to the testing of many additional compounds and to continued investigations of the nature of the biological effects. In 1938, Koepfli, Thimann, and Went⁶⁴ first proposed the qualifications they considered necessary for a compound to be active in the split-pea curvature test: (a) a ring system as nucleus, (b) a double bond in this ring, (c) a side chain, (d) a carboxyl group (or a structure readily converted to a carboxyl) on this side chain at least one carbon removed from the ring, and (e) a particular space relationship between the ring and the carboxyl group.

Further work soon indicated some defects in this list of requirements since compounds were found which met the requirements but were inactive, and others which did not meet the requirements were active. Various modifications have been introduced subsequently by a number of workers. The whole subject of relation of structure to activity is discussed in an excellent review by Veldstra¹¹².

A structural feature that has received considerable attention recently is the suggested necessity of the presence of a hydrogen atom on the carbon adjacent to the carboxyl group as first proposed by Osborne and Wain⁸⁷ and further elaborated by Osborne, Wain, and Walker⁸⁸ in a series of aryloxy-alkylcarboxylic acids. Hansch and Muir⁴¹ and Muir, Hansch, and Gallup⁸¹, as a result of their studies with a series of substituted phenoxyacetic acids, concluded that growth regulants may be considered as reacting with a substrate at two points, at the carboxyl group and at a position *ortho* to the attachment of the carboxyl group. However, 2,3,6-trichlorobenzoic acid which has been found to be highly active by Bentley⁷ does not have a free *ortho* position. The activity of this compound has been explained by Muir and Hansch⁸⁰ in broadening this work to include the benzoic acid derivatives, on the basis of reaction with the substrate by the chlorine in the *ortho* position instead of the hydrogen atom. Later Hansch, Muir, and Metzenberg⁴² suggested that chloride ion was released when 2,6-dichlorobenzoic acid produced elongation of *Avena* coleoptile sections. The rather sparse data produced have been questioned by Veldstra and van de Westeringh¹¹³ who also found some release of chloride ion from 2,4-dichlorobenzoic acid which is inactive.

The possible importance of the *ortho* position and a two-point attachment as a first step in the action of growth regulants is also stressed in the review by Bonner and Bandurski¹³. Support is given to the suggestion of Hansch, Muir, and Metzenberg⁴² that the carboxyl group may become involved in a peptide or other amide linkage, and that the *ortho* position may react with a sulfhydryl group such as the SH group of protein bound cysteine. It has been shown by Thimann and W. D. Bonner^{106, 107} that reagents such as iodoacetate, arsenate, *p*-chloromercuribenzoate, or unsaturated lactones which oxidize or combine with SH groups inhibit the growth regulant effect. This indicates that the growth-regulant reaction is dependent on SH groups. Bonner and Bandurski¹³ do not think that the results with the substituted benzoic acid derivatives are at variance with the two-point attachment hypothesis but that instead they tend to emphasize the importance of the *ortho* position in the reactions of auxins. On the other hand, Veldstra and van de Westeringh¹¹³ point out that in the two-point attachment hypothesis the space between the *ortho* position and the carboxyl group is probably not unimportant. The *ortho* positions in the phenoxy acids, benzoic acids, and others, are by no means equivalent in this respect.

Mechanism of Action of Growth Regulants

The plant physiologist and plant biochemist are naturally very much interested in determining by what mechanism the various growth regulants exert their effects. A better understanding of what processes are directly influenced would inevitably lead to better methods of testing for new growth regulants and therefore to more rapid advances in this field. Much work has been done along these lines following chiefly three main avenues of attack: (a) a study of the effect of various growth regulants on isolated plant enzyme systems, (b) a comparison of the enzyme contents of growth regulant treated versus control tissue, and (c) studies on effects of the regulants on the chemical composition of plants. The studies involving isolated enzyme systems and a number of synthetic growth regulants are presented in tabular form in a recent review by Bonner and Bandurski¹³. Included are about fifteen enzymes concerned mostly with oxidative or other respiratory processes, and a number of the more common synthetic growth regulants. In some instances the regulants inhibit and in others they stimulate the activity of the enzyme being studied. The reviewers conclude that there is as yet no evidence that any of the effects reported are of physiological importance.

Studies of the enzyme activities of treated tissue as compared to comparable control tissue have likewise brought out many differences, some involving increases and others decreases in the enzymes considered. In this area, too, interpretations are difficult, in part, because comparison is being made between growing and nongrowing tissue.

The effect of regulants on chemical composition has recently been reviewed by Mitchell⁷⁹, by Blackman, Templeman, and Halliday¹⁰, and by Crafts¹⁷ with emphasis on the compounds active as herbicides. Many changes in activities of various enzymes and in chemical constituents as a result of exposure to chemicals have been reported. It has not been possible, however, to determine which of the effects observed, if any, are crucial for the physiological action or specificity of the regulants studied.

Need for Growth Regulants Producing Responses Not Now Controlled

Although the catalog of effects that can now be produced by chemicals is a long one and the advances have been brought about in relatively few years, there are still many additional responses being investigated. Needed are chemicals which will control flowering for many species of plants, as are now available for pineapple. A method of delaying flowering or hastening it would find wide applications. Initiation and control of shoot growth would also be useful. For years plant physiologists have been searching for ways to stimulate plant growth to bring about earlier maturity with the same or preferably increased yields. A field which remains comparatively untouched

is the use of chemicals to influence plant composition along desired lines. Since the diet of many people all over the world is deficient in protein, a means of increasing the protein content of crops is an extremely important objective. Better chemicals to bring about defoliation would also be very valuable. Many other useful applications of chemicals to plant growth will occur to those interested in this field and there is no doubt that many important advances will be made in the near future.

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7. ENZYMES

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Introduction

All living organisms carry on a series of rather intricate and involved chemical reactions. One of the surprising things about these reactions from the standpoint of a chemist is that the living cell can carry them out under such mild conditions of temperature, pressure and hydrogen ion concentration. The cells are able to do this because they contain an efficient system of catalysts which they synthesize themselves. We call these catalysts enzymes. Their properties and the role that they play in some agricultural products is the subject of this chapter.

Practically all reactions that occur in living cells are dependent either directly or indirectly on enzymes. Since enzymes remain active long after the cells that produce them cease to live any product may contain enzymes if it is produced from an organism that is living or once was living, by methods that do not destroy enzymes. Most agricultural products are in this category.

Like all living matter microorganisms contain enzymes. Microorganisms are very widely distributed in nature, being abundant in the soil and normally always present in the air. Practically all agricultural products contain them in quantities ranging from a relative few to very large numbers. It is not always easy to distinguish between enzymes native to a product and enzymes contributed to the product by microorganisms. Practically, it may not be necessary to distinguish between them but both must be recognized.

Agriculturalists have an interest in all forms of living matter and hence in all aspects of enzymes. Food chemists are most interested in reactions that occur in agricultural products between the time of harvesting, or preparation, and their use by the ultimate consumer. If the properties desired in a product are optimal at the time of harvest, or preparation, then subse-

quent enzyme reactions are detrimental and should be minimized. On the other hand, if the product needs to mature after harvesting, or preparation, then the enzymatic reactions involved must be encouraged. Both cases occur, sometimes in the same product. In such cases a compromise is often adopted but a real solution sometimes exists in the ability to add more of the required enzyme and thus hasten development of the desired property.

General Properties of Enzymes

Enzymes are organic compounds that have the special property of being able to catalyze the interaction of other chemical substances. This property enables them to accelerate certain reactions without being irreversibly altered by the reactions. As a result they can act over and over again so that one molecule of catalyst can accelerate the reaction of many molecules of the reacting substances.

Catalytic reactions are reversible under the proper conditions and many enzymatic reactions show this property. In individual organisms we have long recognized an anabolic and a catabolic type of metabolism—the one building up compounds and the other breaking them down. In a general sense one is the reverse of the other and both are enzymatic. In a much stricter sense individual enzyme reactions are reversible. For example, the enzymatic conversion of one molecule of hexose diphosphate to two molecules of triosephosphate is a reversible reaction. One can start with the enzyme plus either the hexose diphosphate or the mixture of triosephosphates and soon obtain the same equilibrium mixture containing both the hexose and triose compounds⁴³. It does not follow that the general reversibility of metabolism results from the reversal of each individual reaction. There may be more than one enzymatic procedure for producing a given compound. Each procedure may be truly reversible, under the proper conditions, but under the conditions prevailing in the living cell one reaction may be highly favored over the others. Any given compound may be broken down by one procedure and built up by another. The over-all result looks like a reversal, but the individual steps in the reaction were not reversed. In fact, this is the usual procedure in the cyclic type of reaction commonly found in living cells¹⁶.

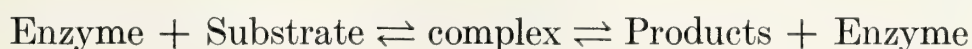
A number of enzymes have been isolated in crystalline form and in some cases these crystals meet all the applicable tests for a pure compound⁴⁹. In each case the crystalline enzyme has proved to be protein in nature and it is a common assumption that all enzymes are proteins. Whether this generalization proves to be correct or not, many enzymes have been demonstrated to be proteins. In some cases they are simple proteins, which means that they are composed entirely of amino acids, and in others they contain other substances in addition. In a number of cases metals such as iron,

manganese or zinc are combined with the protein and are an essential part of the enzyme. In other cases organic, but nonamino acid, portions are attached to the protein molecule. Examples are the heme group and various vitamin derivatives. The firmness with which the nonamino acid portion is attached to the protein is subject to considerable variation. In the case of the enzymes containing the heme group, the attachment is firm and there is no hesitation in saying that the heme group is part of the enzyme. In the case of some of the vitamin derivatives the attachment is less firm and a readily measurable equilibrium exists between the free and combined vitamin derivative. It is then a question whether the vitamin derivative should be considered as part of the enzyme or as a coenzyme. In any case it is an essential part of the catalytic system. It seems probable that all essential materials that are required in only trace amounts, such as the so-called trace elements and the vitamins, function as component parts of catalytic enzyme systems²¹.

Proteins as a class possess a number of properties that have been found characteristic of all enzymes that have been studied. For example, they are large molecules that do not diffuse through membranes of cellophane or collodion, they are readily denatured by heat or by a variety of other procedures and they are very sensitive to changes in the acidity or alkalinity of their environment. Their complexity of structure enables protein catalysts to be very specific in the reactions that they catalyze. For example, they easily distinguish between the L- and D-forms of various compounds, reacting readily with one and not at all with the other. Such specificity is the most characteristic property of enzymes and differentiates them from most other catalysts.

People have long speculated on how enzymes act. One of the early attempts at treating the kinetics of enzymatic reaction mathematically was that of Michaelis and Menten⁴⁴. Their basic postulate was that the enzyme combined with the substance that was to undergo reaction. Most authorities today accept such combination and indeed there are some direct experimental observations¹¹ as well as a host of inferred conclusions to support it.

We may express the Michaelis-Menten concept in the following way:



The formation of the complex is at least a bimolecular reaction while the two possibilities for breakdown of the complex to give either the original reactants or the products are monomolecular reactions. Consideration of the equation shows that we could measure the over-all progress of the reaction by measuring either the disappearance of the substrate or the appearance of the products. If we consider the rate of formation of products then obviously this rate will be proportional to the concentration of com-

plex. It is also obvious that the concentration of complex depends on the concentrations of both enzyme and substrate. In many practical cases, however, the concentration of enzyme will be small compared to that of the substrate and in such cases we may expect that most of the enzyme will be combined as complex. The rate should then be directly proportional to the concentration of enzyme and independent of the concentration of substrate. Actual experimental results bear out these expectations. The rate at the point where substrate concentration ceases to have an effect is referred to as the limiting rate. The enzyme is then working at full capacity under the given conditions. In well defined systems it is possible to calculate the number of molecules of substrate that are converted to products per molecule of enzyme per unit of time. This number of molecules is often referred to as the "turn over" number of the enzyme. In some measured cases this number is almost unbelievably large (two million per minute)⁴. When the rate of reaction is equal to half the limiting rate the concentration of substrate is commonly referred to as the Michaelis constant for the enzyme. The mathematical reason for choosing this point is that at this point the rate constant for the reaction is numerically equal to the concentration of substrate. Such Michaelis constants are now known for a considerable number of enzymes. They vary widely which indicates that the affinity of different enzymes for their substrates is far from constant.

As stated earlier, enzymes are large molecules. It is thought that certain portions of their surface are active centers and that the substrate must combine with the enzyme at these active centers. The nature of an active center is not clear although some things are known about them. In some cases contact between the enzyme and the substrate at one point may be sufficient. In others, multiple contact (at least three points) seems to be required⁵⁰. In such a compound the substrate is said to be in an activated state. If the reaction involved consists of splitting one molecule of substrate to form two new molecules, then we may consider that when the substrate is combined with the enzyme the electrical forces holding the atoms together are altered to such an extent that rearrangement of the atoms is favored. If the reaction to be catalyzed consists of the interaction of two substances, it also may be necessary for the second substance to combine with the same enzyme molecule. The nearness of the two activated substrate molecules on the surface of the same enzyme molecule may then permit the interaction. In other cases it may not be necessary for the second substrate to combine with the enzyme. For example, in the hydrolysis of a peptide link, the peptide combines with the enzyme. There is no clear evidence about whether or not the water needs to combine with the enzyme. The peptide activated by combination with the enzyme may react with ordinary water which is normally always present in high molar concentration.

As stated previously enzymes are proteins, made up of amino acids and

therefore they contain some free amino and carboxyl groups. These groups ionize with changes in pH and as a result, the enzyme molecule becomes charged. At the isoelectric point the charge is at a minimum. It may be actually zero or only the net charge may be zero. On the acid side of the isoelectric point the enzyme will carry a positive charge and on the alkaline side a negative charge. The amount of charge is determined by the amino acid pattern of the particular enzyme and by the pH. It seems unlikely that differently charged enzyme molecules could be equally active catalytically so we might expect that enzyme activity will be a function of pH. If the substrate also carries a variable charge, e.g., if the substrate is also a protein, then the effect of pH is very complex. In most cases the activity of an enzyme is optimal in a certain pH range and drops off on both sides, although the two halves of the curve may be quite different. In some cases the optimum range is very narrow, but in others it extends for about a pH unit. When ionization is the only factor involved, the activity of an enzyme approaches zero asymptotically at extremes of pH. Such an effect is fully reversible and the enzyme can be restored to full activity by readjusting the pH. However, enzymes have a complicated structure and in many cases the structure is stable only in certain pH ranges. Exposure outside of these ranges causes irreversible inactivation. Since individual enzymes are quite different, generalizations are difficult, but it is certainly true that most enzymes are destroyed by strong acid or alkali.

The rate of chemical reactions is influenced by temperatures being greater at higher temperatures. The same thing is qualitatively true for enzymatic reactions, but in this case the effect is complicated by the fact that the enzyme is heat labile. Aqueous solutions of an enzyme lose activity when heated. Again individual enzymes are quite different but in most cases the rate of loss becomes appreciable at 50°C and quite rapid at 60°C and above. With rare exceptions this loss is irreversible. The effect of this instability, coupled with the usual effect of temperature on reactions, is that enzymatic reactions have an optimum temperature and decrease in rate above the optimum. The precise position of the optimum depends upon the period of time over which the measurement is made, for the destruction by heat is also a time reaction. The shorter the period of measurement, the higher the optimum found. The heat stability of an enzyme can be varied by a number of factors. A common one is the presence of substrate. Presumably the substrate combines with the enzyme and stabilizes it. A molecule chemically similar to the substrate may have a similar effect. The salt content of an enzyme solution and, of course, the pH of the solution also exert considerable effect on heat stability. In the solid state, if moisture is absent, enzymes are much more stable to heat and may retain full activity until the temperature becomes high enough to char them, i.e., above 100°C.

The fact that enzymes are large molecules limits their diffusibility. If

the substrate is also a large molecule it is sometimes impossible to bring the two together in a living cell. Most studies of enzyme reactions have been made in homogeneous solutions. It is quite sure, however, that reactions often occur at interfaces or when one reactant is insoluble. A common example is the action of a water-soluble lipase on a water insoluble fat. In order to get a good rate of reaction, formation of an emulsion is essential. In some industrial applications of enzymes the substrate is definitely not in solution. Thus, in removing a starch "size" from a textile fabric by an enzyme, the enzyme must act on an insoluble film. Some water is essential, however, and even reactions that do not involve water will not take place with dry reactants.

Some enzymes are susceptible to oxidation and are inactive when oxidized. Thus, the enzyme urease contains sulfhydryl groups that are readily oxidized to disulfide groups⁶⁵. The disulfide form is inactive, but it can be reduced back to the sulfhydryl form which is again active. On the other hand some enzymes, such as rhodanase (rhodanese), are active only in the disulfide form⁶³. Not all enzymes contain groups that are readily susceptible to oxidation or reduction, but strong oxidizing agents will inactivate most of them and such oxidations are not reversible.

Most enzymes are inhibited by heavy metals. Thus, silver ion is usually a strong inhibitor. In those enzymes that contain sulfhydryl groups in their active form the heavy metal may act by combining with the sulfur. However, proteins in general combine with heavy metals and such metals are often used as protein precipitants. Such general nonspecific reactions may account for some of the inhibitions. In cases where the active enzyme contains a metal, other metals may replace it to give a less active or inactive product.

Specific enzyme inhibitors that appear to be peptide in nature are known to occur in some natural products such as soybeans²⁵. They react with an active enzyme such as trypsin, for example, to form an inactive compound. Under certain conditions the reaction can be reversed. Such inactivated enzymes bear some resemblance to natural enzyme precursors such as trypsinogen.

Enzymes can often be inhibited in other ways⁴¹. Removal of certain groups by reaction with various chemicals is one way. Thus some enzymes that contain sulfhydryl groups readily react with a reagent such as iodoacetic acid, converting the sulfur to a thioether and giving an inactive product. Other enzymes are inactivated by removing the free amino groups or by blocking them by conversion to various derivatives. Others are inactivated by substituting halogens into the aromatic ring of the tyrosine contained in their molecule. Such reactions are usually nonreversible. A general method of producing reversible inhibition is by the use of analogues

of the regular substrate⁷¹. The idea is that since the enzyme combines with the substrate it will also combine with a molecule that "looks like" the substrate even though the latter cannot undergo any reaction as a result of the combination. Thus, malonic acid inhibits the enzymatic oxidation of succinic acid. Such combination will usually be reversible just as combination with the substrate is reversible. If such an analogue and the regular substrate are both present they will compete for combination with the enzyme and the inhibition obtained will be a function of the ratio of the two concentrations. The importance that this way of producing inhibition has is that it forms a much needed rational basis for choosing an inhibitor for any enzyme that has a known substrate.

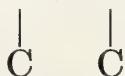
Types of Reactions Catalyzed by Enzymes

It is usually stated that a catalyst does not initiate a reaction, but merely accelerates a reaction that would occur more slowly without the catalyst. Since a catalyst does not provide any energy but merely alters the path by which an energy change can occur there is, in most cases, little reason to question such a statement, particularly if we grant that the acceleration can be very great indeed. With enzymes, however, there may be some doubt about the applicability of such a limitation. Certainly some enzymes do catalyze reactions that occur readily in their absence. An example is the release of CO_2 from a solution of bicarbonate by carbonic anhydrase, according to the equation: $\text{HCO}_3^- \rightleftharpoons \text{CO}_2 + \text{OH}^-$. The uncatalyzed reaction occurs perfectly well and the only apparent need for an enzyme is that the reaction does not go fast enough for physiological purposes. On the other hand, if we consider the reduction in an aqueous medium of the carboxyl group of a compound like phosphoglyceric acid all the evidence available to us makes it seem unlikely that it would go at all without enzymes although it is relatively easy to arrange an enzyme system with which it goes readily. The important point would seem to be the ability both to direct the course of a reaction and to mobilize energy from one reaction and apply it to another²⁰. The ability to "couple" reactions in such a way that the energy released by one is utilized to drive another may make some enzymes a rather special kind of catalyst and may enable them to initiate reactions. Once this "coupling" is mastered it seems likely that, under proper conditions, any possible chemical reaction can be catalyzed by an enzyme or a group of enzymes. Practically, most reactions that occur in living cells are catalyzed by enzymes. When textbooks classify types of enzymatic reactions they are merely classifying the types of reactions known to occur in living cells or preparations made from them. Our knowledge of these reactions is rapidly increasing and many reactions that are now well demonstrated were unknown a few years ago. Many additional reactions undoubt-

edly occur that have not been demonstrated. Possibly somewhere among the diverse forms of living matter every possible reaction occurs. In isolated enzyme systems, of course, only those reactions occur freely that result in a decrease in free energy. If the reaction requires energy, some provision must be made to provide it before the reaction can go. We are learning to do this in isolated systems and living cells are well equipped to use the energy from one reaction to drive another.

Basically, the known reactions are few in kind. One type consists of converting one molecule to two. We may represent it by the equation: $A \rightarrow B + C$. The reverse of this reaction ($B + C \rightarrow A$) of course joins two molecules to form one. An example of both reactions is the one cited above where hexosediphosphate and two triose phosphates form an equilibrium.

In a somewhat similar type the linkages in a molecule may be rearranged, apparently without the participation of other molecules. We may represent it as follows: $A-B \rightleftharpoons A-B$. The conversion of a straight chain of



glucose units with 1:4 linkages to a branched chain with a 1:6 linkage is one example. The conversion of an alpha to a beta glyceride is another.

Another type involves the interaction of two molecules with the result that each one is split into two parts and the parts rearranged to form two new molecules. We may represent it by the equation: $A + B \rightleftharpoons C + D$. A very common example is the one in which A or B is water. In this case the reaction running to the right is called an hydrolysis and the one running to the left a condensation. Another closely analogous example employs phosphoric acid or its salts instead of water. Many of the reactions commonly called transfer reactions belong to this type as do many oxidation-reduction reactions. Most reactions can be reduced to one of the types given.

In a normally metabolizing living cell the contents are in a very dynamic condition and many different enzymatic reactions are occurring simultaneously. As long as some outside source of energy is available in the form of food that can be utilized, individual reactions that require energy can readily occur. When an outside source of energy fails, as when an animal must fast or a plant is harvested, normal metabolism is maintained for a while at the expense of reserve materials that can be utilized. As soon as the reserves are depleted the only source of energy remaining is the structural material of the organism. Since enzymes that can attack it are present such structural breakdown may not be long delayed.

Naming of Enzymes

Unfortunately, there is no generally accepted system for naming enzymes. In recent years there has been considerable agreement that a name

should be as informative as possible about the reaction catalyzed, but it is difficult to be truly informative without developing a very awkward system. The usual procedure is to take the name of the substrate and add the ending *ase*. Thus, an enzyme that acts on a protein becomes a *proteinase*, an enzyme that acts on starch an *amylase*, etc. The obvious limitation of such a system is that it doesn't indicate the nature of the reaction that occurs on the substrate. In the cases of *proteinase* and *amylase* one must know intuitively that the reaction in question is hydrolysis. However, when one is confronted with a name like *cysteinase* it is difficult to know, even intuitively, what reaction is involved. The name should indicate the reaction as well as the substrate whenever possible e.g., *glucose dehydrogenase*, *D-amino acid oxidase* etc. Of course, some of the older names such as *pepsin* and *trypsin* are almost as well established as the word *enzyme* itself and they will very likely never conform to any system.

Control of Enzymes

It is often essential in handling agricultural products that the action of the enzymes be controlled. The means available to us for such control follow directly from the properties of enzymes previously discussed. For example, contact between the enzyme and its substrate is necessary for reaction. If contact can be prevented, control is complete. In most cases, however, contact cannot be prevented, so other means must be employed.

Temperature is perhaps the most common means of control. All chemical reactions, including enzyme reactions, go more slowly the lower the temperature. Refrigeration thus frequently gives adequate control although it does not completely stop enzyme action³⁵. At the other extreme, enzymes are heat labile and in most cases can be permanently destroyed by a relatively mild treatment. There are cases known where, under certain conditions, an enzyme may be inactivated by heat and regain its activity by subsequent treatment. Such reactivation can occur in agricultural products⁶. One must distinguish here between enzymes native to a product and enzymes contributed by microorganisms. Many microorganisms are destroyed by a heat treatment that destroys enzymes, but certain ones — particularly spore-formers — may survive. If conditions permit, they may subsequently multiply and in so doing produce more enzymes. Refrigeration would, of course, keep such growth to a minimum.

Desiccation is another general method of controlling enzyme action. The main problem is to get and maintain a sufficiently dry product. In general, the growth of microorganisms requires more moisture than enzyme action does.

Removal of oxygen is another way of controlling some products. It stops those enzyme actions that require direct participation of oxygen, stops the

growth of aerobic microorganisms and stops autoxidations. Some of these effects can also be obtained in certain cases by the use of antioxidants.

In some cases it is possible to change the pH of a given preparation enough to control certain enzyme reactions. In most cases a shift of two pH units to either side of the optimum is enough to cut the rate of reaction to a few per cent of its previous value. Obviously, such a method must be applied with care if a group of enzymes is present, for a change that might hinder one might activate another.

There are some relatively recent physical treatments that may become practical means of controlling enzymes. Perhaps the best explored one is treatment of a product with a high-speed electron beam⁵³. Under certain limited conditions ultraviolet light⁴², x-rays¹⁴ and ultrasonic waves⁴⁶ can inactivate enzymes.

If one particular enzyme reaction is causing trouble the situation can usually be remedied if it is possible to remove or alter the substrate. Such change can sometimes be done by chemical means, but the number of chemicals that can be used on a food product is limited. It can sometimes be done by adding another enzyme that will act on the substrate and convert it to an innocuous substance⁶².

Chemicals can be added to inhibit the reaction of various enzymes. It seems probable that many drugs, antibiotics, insecticides, fungicides and bactericides act by interfering with enzyme action in the organism they act upon. Although these products are widely used in agriculture their direct addition to food is very limited. As our knowledge of enzymes increases the possibility of being able to inhibit an essential enzymatic reaction in one living organism without also inhibiting an essential reaction in some other organism will undoubtedly increase.

Enzymes and Agricultural Products

Grain and Flour. From the standpoint of quantity involved, grains are one of the main agricultural products. They are to a large extent a storage form of food and it may be instructive to see how nature protects the stored food from the enzymes that could act on it. One principle employed is physical separation. In wheat, for example, the enzymes are largely confined to the germ and to a lesser extent to the aleurone layer, while the large endosperm contains much of the stored food and very little in the way of enzymes³. Similarly in oats the lipase is almost entirely located in the outer pericarp layers⁵¹. In sugar cane the juice is rich in sucrose while the tassel of the plant contains a relatively high concentration of the enzyme invertase that hydrolyzes sucrose³¹. For this reason it is common practice to detassel sugar cane before harvesting it.

Another principle employed is that of desiccation. Wheat, for example, normally does not contain more than about 13 per cent moisture which is

very low as living matter goes. Specific enzyme inhibition is also employed so that some of the enzymes present are in an inactive state and remain so during normal storage. The net result is that grains which are potentially able to cannibalize (autolyze) themselves may be safely stored for long periods.

It is, of course, essential for nature's purpose that the dormancy of stored grains be easily broken so new growth may occur. As every agriculturalist knows, moisture and a favorable temperature are about all that is required. The dormant grain then sprouts and begins to grow. The details of this important process are not all known, but in a general way we know that the enzymes present become activated, new enzymes are formed either from complex precursors or by complete synthesis, and the walls or membranes separating the individual sections of the grain kernel are gradually broken down giving the enzymes free access to the stored food which is then utilized to form the growing sprout. This process can be arrested, leaving many of the enzymes active, by a drying process known as kilning. Malting of grain consists of just such a germination followed by kilning¹⁵.

When grains are used for food they are usually converted to flour. In this process the germ, with its relatively high enzyme content, is separated physically and removed. The outer layers of the kernel, including the aleurone layer, are removed as bran. The remainder is crushed to produce flour. Such flour from sound grain is quite low in most enzymes except beta amylase and the quantities that are present are normally quite inactive due to the low moisture content of flour. In industrial uses of grain an analogous removal of the germ is usually employed although there may be other reasons beside the removal of enzymes for doing so.

When grain flour is employed in baking, its enzyme content becomes a matter of considerable importance¹⁹. For best results it is usually necessary, although to a varying extent on different flours, to modify both the starch and the protein of the flour³³. As stated above most flours contain beta amylase, but this enzyme by itself does not sufficiently modify the starch. Alpha amylase is usually required. In recent years millers have usually added some malted wheat, or, less frequently, malted barley to their flour to increase the enzyme content. The opportunity that grain may have to sprout between cutting and milling is, of course, a factor in determining the enzyme content of the flour. In addition to the enzymes added by the miller, bakers also frequently add enzymes. In recent times bakers have found that commercial preparations of fungal enzymes give them excellent results and enable them to adjust the ratio of amylase to protease to suit their needs⁶⁰. Use of such fungal preparations has been approved in the bread standards. The enzyme lipoxidase is also used in baking practice to bleach flour²². Other enzymes such as lipase and pentosanase probably also play some role.

Meats. Meats prepared from freshly killed animals contain a wide as-

sortment of enzymes. They also offer a very desirable medium for the growth of many microorganisms. Problems concerned with the keeping of meats are usually a combination of problems in the control of both enzymes and microorganisms. The most common control employed is refrigeration. If the temperature applied is low enough, e.g., if the meat is frozen, growth of microorganisms may be close to zero and enzyme reactions are much retarded, but not stopped. Even frozen meat has a strictly limited storage time for maximum quality.

Some aging of meat is usually considered beneficial³⁸. Unless precautions are taken to prevent the surface growth of microorganisms the effect of aging is apt to be due to both enzymes and organisms. One beneficial enzyme effect that occurs is the partial breakdown of proteins in the connective tissue and the muscle fibers. As the result of such a breakdown the meat is made more tender. This result can be accelerated by adding a protease in the form of a "meat tenderizer." One harmful enzyme effect that occurs during aging is the hydrolysis of fats which is sometimes followed by oxidation and the development of rancidity.

The color of meat is an important factor in its appearance. The color is largely determined by the state of the hemoglobin type compounds present and this state is at least indirectly affected by the enzyme reactions that can occur in the tissues. The reactions that can occur are determined in part by the enzymes present, but also in part by the substrates present. In many meats the concentration of substrate present may be somewhat abnormal because the animal was in a state of shock at the time of death. There is actual experimental evidence⁷⁰ that injection of insulin before killing lowers the blood sugar, raises the tissue pH and tends to produce "dark cutting" meat. Possibly recent approaches to the problem of feeding before killing and the manner of killing¹ may influence this problem.

There are a number of other ways of influencing the enzyme reactions of meat. Cooking, of course, destroys all the enzymes. In the process known as precooking, the temperature reached is usually high enough to destroy most enzymes. Removing the moisture present also effectively stops the usual reactions. Dried meats are, of course, an ancient product. Pickling, dry curing and smoking are other procedures commonly applied to certain meats that may influence the enzyme reactions.

Fish. Fish is usually considered more perishable than meat. For one thing the digestive tract may contain powerful proteases that, after death, rapidly perforate the intestinal wall⁵⁴. The enzymes, as well as the bacteria present in the intestinal tract, are then free to attack the surrounding flesh. It is therefore good practice to gut and wash fish promptly. To some extent this same precaution applies to poultry although the reason may be less definitely an enzymatic one. The odor of trimethylamine which is often

described as "fishy" is not present in fresh fish. Its formation is probably enzymatic, but one enzyme concerned in the reaction is thought to be produced by growth of a bacterium⁶⁷. The oxidation of fish fat occurs readily. It is probably not enzymatic but largely due to autoxidation catalyzed by hemin compounds.

Dairy Products. Milk is another agricultural product in which it is difficult to distinguish between enzymes native to the product and enzymes produced by microorganisms growing in the product. The distinction is made difficult by the fact that milk contains microorganisms while it is still in the udder. The evidence indicates that in normal udders the lactiferous ducts, even the very minute ones, may harbor bacteria that infect the milk as soon as it is secreted²⁹. Nevertheless, there is general agreement that milk contains several enzymes of animal origin³². The commonly recognized ones are protease, amylase, lipase, phosphatase, catalase and peroxidase. What is frequently referred to as reductase is also present. It probably consists of one or more dehydrogenases. It is well known because it forms the basis of the Schardinger test. In this test milk reduces the dyestuff methylene blue when an aldehyde is also added.

The normal enzyme content of milk is sufficient to cause significant changes in the product on storage even if the growth of microorganisms could be entirely prevented. Thus, the protease would gradually break down the casein and other proteins, and the lipase, or lipases⁵⁹, would hydrolyze the fats. The latter reaction is greatly aided by homogenization which effectively increases the surface of fat particles exposed to the enzyme action. The free fatty acids produced may result in the formation of a bitter flavor which is normally objectionable in fluid milk but desired in certain products.

Aside from refrigeration which is almost universal in this country, the usual procedure for controlling such enzyme action is pasteurization of the milk. This heating procedure normally destroys most enzymes as well as most of the microorganisms present. Tests for remaining enzyme activity are commonly used as a check on the efficiency of the pasteurization. Phosphatase activity is frequently employed in this way. The level of enzyme activity has also been suggested at various times as a test for milk quality. Thus, milk drawn from a diseased udder has been shown to have higher amylase and catalase activities⁵⁷. Similarly, in old milk most of the high catalase activity present is of bacterial origin. Some of the milk enzymes, such as the protease and lipase, are thought to play an important role in the ripening of cheese^{2, 8, 48}. It thus makes considerable difference whether cheese is made from raw or pasteurized milk.

Drying is another widely used method of preparing milk for storage. The temperature employed is usually high enough to destroy most enzymes, but

those that survive can be controlled by absence of moisture. However, as mentioned with other products it is easier to prevent growth of organisms than it is to prevent enzyme action by drying²⁴.

There are a number of known applications in which enzymes are added to milk. Perhaps the best known one is the use of rennin to clot milk. Rennin is a proteolytic enzyme normally prepared from the lining of the fourth stomach of young calves or lambs. It is very effective in clotting or coagulating milk and forms a curd that is readily digestible and easily freed of mother liquor. It is therefore widely used in the cheese industry⁵⁷. Other proteases are sometimes added to milk to influence the curd subsequently produced⁶⁴ or to influence the stability of concentrated milks⁶⁶. Pancreatic proteases have also been used as antioxidants in milk^{17, 47}. Various enzymes have been added to influence the manufacture and ripening of certain cheeses^{18, 58}. Malted milk, of course, contains all the enzymes of regular malt. The enzyme lactase has a number of indicated applications. Milk normally contains about 5 per cent lactose. Among the common sugars lactose is one of the least soluble and one of the less sweet. In certain dairy products such as concentrated milks, ice cream and certain processed cheeses the lactose present has a tendency to crystallize. In some cases such crystals have been confused with the presence of ground glass. In ice cream such crystals are the cause of what is known as sandy ice cream. In stored concentrated milks the precipitate that develops is very difficult to redissolve or even to remove from the container. Such crystallizations and precipitations can be prevented if the lactose is partially hydrolyzed by lactase. In cases where lactose is not efficiently utilized in feed (e.g., in poultry), hydrolysis of such products as whey with lactase has been claimed to improve their nutritional value.

Eggs. From the standpoint of numbers produced eggs are a very important agricultural product. Nutritionally they are also one of our most important foods. The fact that the neatly and efficiently packaged egg contains everything necessary for the development of a complete chick, with the exception of adequate oxygen, testifies to its high nutritional value and also shows that it must contain some preformed enzymes and must be capable of synthesizing others. In this case microorganisms need play no role. The normal egg contains few if any microbes and those that may be present are apparently prevented from multiplying, possibly by the lysozyme present. Microbial spoilage becomes a factor only when the microbes have gained entry through the shell and membranes.

The enzyme system of a fertile egg needs only a favorable temperature to begin its task of developing a chick. The process is most conveniently controlled by imposing a low temperature. Eggs do not freeze until well below the freezing point of water. They may be satisfactorily stored in a cold room just below 0°C.

A time-honored method of preserving eggs is to immerse them in water glass (sodium silicate solution). Presumably the solution tends to seal the contents of the egg from any contact with the outside world.

The preparation of dried eggs is a large scale industry. Of course, as soon as the shell is removed microbial contamination is difficult to prevent. For good storage stability of the dried product it is essential that the moisture content be as low as possible. A combination of low moisture, pH control and refrigeration gives adequate stability⁵². Dried egg whites frequently show an objectionable color development as well as physical changes on storage. Glucose plays an essential role in this development. An interesting enzymatic solution to the problem is the addition of glucose oxidase to convert the glucose to gluconic acid which does not show the color development⁵. In the reaction, oxygen is reduced to hydrogen peroxide or water. In order to remove the peroxide formed, or the excess added, some of the enzyme catalase is added with the glucose oxidase. It converts the hydrogen peroxide to oxygen and water. Such reactions are, of course, not limited to egg whites. The same system can be used with excess glucose to remove oxygen from a sensitive packaged product⁶².

Vegetables. At the time of harvest most vegetables are obviously living systems possessing a considerable variety of enzymes. In many cases these enzymes continue their action after harvest. For example, sweet corn is normally harvested when it is in what is known as the milk stage. At this time the corn is busily engaged in synthesizing and storing starch. In fact, the appearance of the milk is thought to be due to starch grains suspended in the liquid. After harvest this synthesis continues, supported, of course, by respiration. The result is that the sugar present in the corn at the time of harvest is rapidly depleted³⁹ partly by synthesis to starch but in part also by respiration. The supply of new sugar is prevented by the separation from the stalk so the corn gradually becomes less sweet. Fortunately, this conversion of sugar to starch is reversible and tends to form an equilibrium when about two thirds of the sugar originally present is consumed. If it were not for this fact, sweet corn picked long before use would not taste as well as it does.

This same reversible conversion of starch to sugar plays a role in other products e.g., in potatoes. Although potatoes can be stored reasonably well, if the temperature is too high the starch will be hydrolyzed to sugars and the latter oxidized. As a result the potato will soften. At lower temperatures the oxidation may be slowed down more than the hydrolysis with the result that the potato becomes sweeter^{12, 24}.

The enzymatic reactions that can occur are by no means limited to carbohydrates. Changes thought to involve fats and resulting in off-flavors and odors occur readily³⁵. Many vegetables contain pectin as a component of their structural composition and also contain enzymes that hydrolyze

it³⁶. Their action causes the appearance of soft spots and if continued may cause the previously rigid structure to soften entirely. Such effects are frequently observed in pickles. Glycosides occur rather widely in plants and their hydrolysis, which frequently follows any breakdown in structure, may cause marked change in taste¹⁰.

The means available for controlling enzymes in vegetables are the same as those previously discussed for other products. Refrigeration is the most common one. It slows down all the reactions concerned and if combined with moisture control gives adequate stability for limited periods. Even frozen vegetables, however, undergo a variety of changes due to enzyme action³⁵. Vegetables are frequently canned and less frequently dried, although drying of some vegetables such as corn is an ancient art. In modern practice before vegetables are either canned or dried they are blanched. This treatment is merely the application of moist heat and one of its main purposes is to destroy the enzymes³⁵. It can be very effective, but if not carefully controlled it can result in objectionable tissue breakdown^{27, 55}. It is also important that the heating-up process be rapid because increase in temperature below the point of enzyme destruction causes an increase in rate of reaction.

Fruits. Fruits, like vegetables, are frequently harvested when enzyme reactions are in full progress. To the extent that no outside materials are required, such reactions will continue after harvest. For example, a well matured but unripe fruit will ripen after harvesting and such ripening is frequently preferred because it can be better controlled. Other factors, of course, enter into such practices, but they are beyond the scope of this paper. The rate of such ripening reactions can be controlled to a considerable extent by temperature. With careful control it is possible for fruits to reach distant markets in top condition. Such control is limited, however, and eventually the structure of the fruit will break down. To some extent chemicals can be used to influence one or more reactions in whole fruit, e.g., ethylene can be used to "artificially" ripen a fruit. Among its effects, it probably destroys chlorophyll which may mask the color of the normal ripe fruit^{30, 68}.

Considerable quantities of whole fruits are dried merely by exposing them to the sun^{37, 45}. They are usually treated with sulfur or some preparation to control microbial growth. The dry product keeps better than fresh fruit, but it seems unlikely that it ever gets dry enough to stop enzyme action.

Large amounts of fruits are processed in various ways. In most cases the original structure is altered and as a result microbial attack is facilitated and any physical separation of enzyme and substrate may be disturbed. In some cases only the peel is removed but this exposes surfaces to the air

that were previously protected and in many cases allows enzymatic oxidations to occur that lead to dark color formation. If only temporary protection is required it can usually be obtained by use of some antioxidant such as vitamin C. If more permanent control is needed it is necessary to remove either the oxygen or the oxidizable compound. The latter is usually a phenol type compound often called tannin. Fruits differ considerably in their tannin content and it is possible to influence this content by plant breeding.

Much of the processed fruit is canned and in one of the operations is subjected to a heating action that destroys the enzymes. Much of the remainder of processed fruits is converted to juice. The total quantity and variety of juices have increased markedly in recent years⁶⁹. Some of the products prepared on the largest scale are citrus juice, grape juice, tomato juice and a variety of others of which apple juice is typical. In each of these cases, as well as in many others, the fruit contains a considerable amount of pectin as well as pectic enzymes that hydrolyze it³⁶. The interaction of these components affects the entire process of juice manufacture. In grapes the pectin is largely associated with the structural elements and remains with the skins when the juice is removed. The slimy nature of these structural materials makes complete separation of the juice difficult if pressure is the only aid employed. Hydrolysis of the pectin present, by pectic enzymes, usually results in an increased yield of juice¹³. Freshly pressed grape juice is usually cloudy and rather difficult to filter. In many cases the cloudiness is maintained by the colloidal properties of the pectin dissolved in the juice. If the pectin is hydrolyzed to such an extent that its colloidal properties are destroyed, the suspended matter then tends to settle and can be removed readily by filtration, leaving an entirely clear juice. In both the cases mentioned involving pectin hydrolysis, i.e., in pressing out the juice and in clarifying it, the hydrolysis will occur by the action of the natural enzymes of the grape if one can wait long enough, but it can be brought about in a short time by the addition of pectic enzymes. Pasteurization of the juice then inactivates the enzymes but such inactivation is not essential. The situation with apple juice is very similar to that with grape juice and pectic enzymes are widely used in making a clear product.

With tomato juice, however, the situation is quite different. There is little demand for a clear tomato juice. There is more interest in stabilizing the colloidal cloud originally present. The relative activity of pectic enzymes is much greater in tomatoes than in grapes. The problem then is to heat the crushed tomatoes rapidly enough to a temperature that will destroy the pectic enzymes before they have time to hydrolyze the pectin and, of course, to do so without producing any objectionable taste or odor³⁷. The case of the citrus juices is similar to tomato to the extent that a clear juice is not required. Maintenance of a satisfactory cloud may be even more

difficult. With concentrates, which are popular with citrus products, there is another problem. At least one factor in it is that unless the pectinesterase is completely destroyed it continues, during storage, to slowly demethylate the pectin. The low-methoxyl pectin formed tends, especially in the presence of calcium or similar salts, to precipitate or form a gel. One way to avoid this is to hydrolyze the pectin by means of pectic enzymes before storage. In some cases this approach avoids an undesirable heating period.

Fruits often contain glycosides that on hydrolysis impart a bitter taste to the juice. Such hydrolysis is apt to follow crushing of the fruit which abolishes the physical separation of enzyme and substrate.

The pineapple is an example of a fruit that contains a relatively high concentration of a proteolytic enzyme⁷. The enzyme is called bromelin and is present in such concentration in fresh slices of pineapple that they cannot be used successfully in a gelatin type gel. The latices of a number of other plants contain high proteolytic activity. Perhaps the best known one, although by no means the only one, is papain from the latex of the papaya tree.

Feeds. When green, growing crops are harvested they, of course, contain a variety of active enzymes. This is usually the case with hays. They also offer good culture media for microorganisms. The main practical means of control is to dry the hay before it is stored. The traditional way is to let the sun do the drying. This procedure is economical but it is apt to be slow and permits nutritional damage to the hay during the drying. An increasing practice is rapid drying by mechanical equipment. One of the serious losses that may occur in many hays, in addition to the usual loss of sugars, is destruction of the carotene or provitamin A²⁶.

Soybeans, which are a major agricultural crop, offer two special enzyme problems. They are among the best known sources of two enzymes—urease and lipoxidase. Urease converts urea to ammonia and carbon dioxide. In recent years both urea and soybeans have been widely employed in mixed feeds. If the two untreated products are combined in the same feed the urease will almost surely hydrolyze the urea. The most practical means of control seems to be to heat the soybeans to destroy the urease. Such a process must be carefully controlled or the nutritional qualities of the soybean proteins will be damaged. One recommended procedure²³ is to heat only enough to destroy most but not all the urease. Determination of urease was at one time used as a method to check how much soybean flour had been added to products such as sausage. Lipoxidase catalyses the oxidation of unsaturated fatty acids with the production of peroxides. The peroxides may then interact with other compounds, for example carotene. The enzyme, prepared from soybeans, is utilized commercially to bleach flour by such a reaction on carotene²². The enzyme is important wherever the

stability of fats to storage is involved. It does not seem to be widely distributed in nature and at the present time is not known to play any role in animal or microbial digestion of fats.

The production of silage is an example of preservation of feed by fermentation. Somewhat analogous processes are applied to some foods such as sauerkraut. The main reactions are carried on by microorganisms or by enzymes produced by the microorganisms, although the enzymes of the original crop undoubtedly play some role. Another example where fermentation by microorganisms plays a role is the production of "slops" for hogs. The procedure is to steep whole or ground grains in water or whey or skim milk. Occasionally, more exotic materials such as cooked pumpkins are included. After thorough mixing and aeration the mixture is allowed to stand for a minimum of about 12 hours without benefit of any sanitary control and is then fed. It seems probable that the original materials are ennobled by all the wiles of the fermentation art and it seems possible that many a hog was raised in vibrant good health on an antibiotic-containing slop long before the word antibiotic was invented. It even seems within the realm of possibility that the rising generation of scientific farmers may reappraise the value of a remodeled slop barrel and become less dependent on prepared feeds.

In addition to their use in fermentations, microorganisms also have a direct use as food or feed. Most microbes have a chemical composition quite similar to that of other living matter that is used as food. In some cases they are among the better sources of various vitamins. Some of them, such as certain yeasts, have long had a limited use as food. In recent times there has been much interest in large scale production of microorganisms for food or feed⁵⁶. There are essentially two different approaches. One is the use of a chlorophyll-containing alga, such as a chlorella, that is capable of efficient photosynthesis. With adequate illumination it can produce organic foodstuffs from carbon dioxide, ammonium salts and a very small amount of other inorganic salts, just as such organisms do in nature. The other approach is to use a non-photosynthetic organism, such as yeast, and grow it on inorganic salts plus a carbohydrate source that, under present conditions, is a waste or a positive disposal problem. One such waste is the sulfite liquor from paper manufacture. There is actual large scale production of yeast for feed from such sources²⁸. There is no comparable production of algae⁹. Yeasts, as well as other microorganisms, contain a wide variety of enzymes. If they are to be used as food or feed, control of the enzymes during storage is essential.

Miscellaneous. There are a number of examples where enzymes play a role in the industrial utilization of agricultural products. The retting of flax and other natural fibers is one case. Here the cellulose fiber is freed from

the encasing gums and hemicelluloses either by preformed enzymes or by microorganisms. The removal of adhering gums from coffee beans by an enzymatic solution is a similar case³⁴. The bating of hides with proteolytic enzymes as one step in their conversion to leather is an example from a different field. Proteolytic enzymes are also used in food preparation. Thus the proteins of whey can be hydrolyzed to produce an attractive spread⁴⁰. The whole fermentation industry is largely based on the conversion of agricultural products by microorganisms. Various steps in these conversions are entirely enzymatic. For example, in beer and alcohol production from grain the conversion of the starch of the grain to fermentable sugars is done by enzymes, usually supplied by malt. The finished beer is also often treated with a protease to prevent any haze formation on chilling. Large quantities of grain, particularly corn, are used to manufacture starch. The starch is then frequently modified by enzymes. Among the products produced are soluble starches, sweet syrups, adhesives and sizing for paper. The enzymes used in industrial applications are frequently obtained from microorganisms that are grown on agricultural products⁶¹.

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8. OXIDATIVE RANCIDITY AND ANTIOXIDANTS

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Oxidative rancidity is a well known type of spoilage which occurs in fats and oils and fat components of foods. It results from the action of atmospheric oxygen with the fat or oil molecules and is characterized by a typical, strong and disagreeable odor and flavor. The oxidation or rancid products not only make the food unpalatable but also destroy certain vitamins. The deleterious action of atmospheric oxygen is not restricted solely to fats. Many organic compounds and substances—particularly those with unsaturated bonds or branched chains, such as are found in petroleum products and rubber—undergo similar autoxidation. In many instances the same agents which accelerate or retard the oxidation of fats will have a similar effect on these various organic substances. Hence the mechanism and control of atmospheric oxidation are of widespread interest and importance.

Mechanism of Autoxidation

Some means of envisaging the mechanism of autoxidation is essential for understanding how various factors and agents may accelerate or retard the reaction. The study of the mechanism, products formed, and factors that influence the oxidation has been the subject of a great many investigations for more than fifty years. Considerable progress has been made and an acceptable mechanism has been proposed.

Many of the earliest observations on reactions with molecular oxygen or other gases, and ideas concerning the mechanism resulted from investigations on substances other than fats, such as hydrocarbons, alcohols, and aldehydes. The suggestion that a peroxide is the primary oxidation product

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formed in the direct reaction of molecular oxygen with a substance originated with Bach¹² and Engler and Wild⁸³ in 1897 although the first peroxide was isolated in 1900¹⁴. The earliest attempt to explain the mechanism is attributed to Arrhenius¹⁰, who in 1889 proposed the concept of “activated” molecules. He suggested that there is an equilibrium between normal molecules of a gas and active molecules, the latter being fewer in number but possessed of much greater energy than the average and being the only ones capable of reaction. In 1913, Bodenstein and Dux^{34, 35} proposed the theory of chain reactions which, with modifications such as the free radical concept of chain initiation and propogation, is generally accepted at the present time. The early work in this field has been reviewed by Bailey¹⁷.

The concept of free radicals probably had its origin in the well-known work of Gomberg who prepared triphenyl methyl^{120, 121} and explained the preparation and properties of hexaphenyl ethane on the basis of a free radical reaction¹²². The concept of free radicals has since been frequently applied to explain reactions of the Wurtz-Fittig type, Grignard reactions, photochemical reactions, and many others.

The application of the concept of free radicals and chain reaction to the autoxidation of olefines and polyolefines, including fats and oils, is credited chiefly to a group of British workers^{93, 94, 95, 96, 97, 98, 99, 42}. Since a number of reviews of this work have been published recently^{215, 290, 253, 187, 39, 40, 309} only a summary of the theory and pertinent findings in relation to the problem of oxidative rancidity will be attempted here.

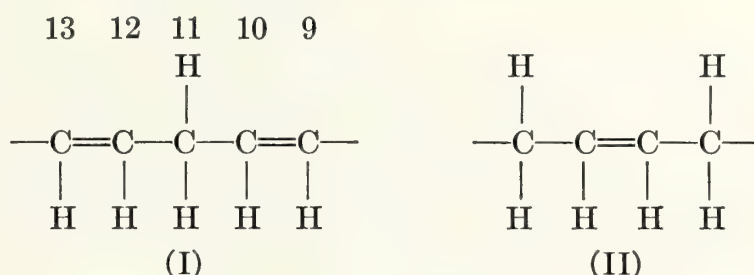
TABLE 8-1. OXYGEN ABSORPTION OF METHYL ESTERS OF FAT ACIDS AT 100°C³⁰²

Substrate		Oxygen absorption	
% Methyl esters	Iodine number	Minutes required to absorb 1 g./kg*	G./kg. at 60 min.
100 linolenate	260.4	7	19.1
100 linoleate	172.4	11	10.2
90 linoleate, 10 stearate	155.2	13	10.0
80 linoleate, 20 oleate	155.0	15	8.4
50 linoleate, 50 oleate	129.0	17	6.6
50 linoleate, 50 stearate	86.2	18	5.0
25 linoleate, 75 stearate	43.1	35	2.6
20 linoleate, 80 oleate	103.0	36	2.9
100 oleate	85.6	115	.2
85 oleate, 15 stearate	72.8	166	.2
57 oleate, 43 stearate	48.8	337	.1
100 stearate	0	1250	.05

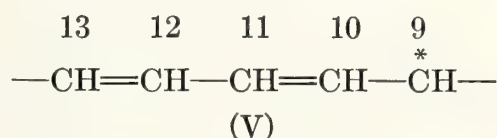
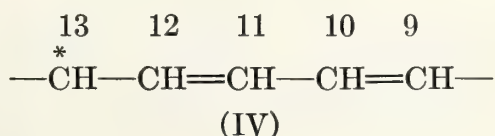
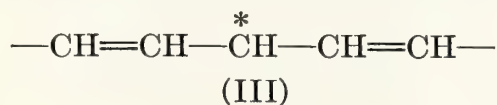
* Amount of absorbed oxygen corresponding approximately to the organoleptic rancid point of most fats.

The polyunsaturated components of fats oxidize many times faster than do the monoethenoid and saturated acids^{147, 170, 318, 302, 148}; in fact, so much faster it is unlikely that any but the polyunsaturated components undergo autoxidation in time required for normal fats to become rancid. The data in Table 8-1 support this conclusion. Some doubt has even been expressed¹⁴⁴ that highly purified methyl oleate undergoes autoxidation at temperatures below 50°C. Linoleic acid is one of the principal acids of our common edible fats—lard, and soybean, cottenseed, peanut, and corn oils. Acids of greater unsaturation, linolenic and arachidonic acids, are often present in minor proportions. Hence, the mechanism of autoxidation of linoleic acid is of prime importance in oxidative rancidity.

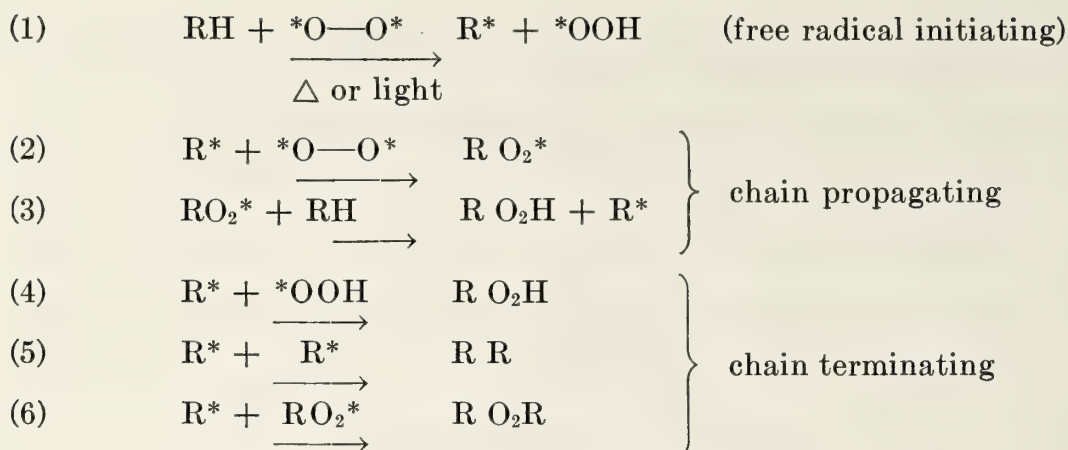
These polyunsaturated acids have in common a methylene interrupted system of double bonds as shown (I) for the pentadiene system of linoleic acid. The two double bonds flanking Carbon 11 greatly increase the lability of the hydrogen atoms on this carbon atom as compared to the influence of one double bond on the adjacent methylenes in oleic acid (II)



Sufficient energy is acquired as heat or light energy to permit the removal of a labile hydrogen from the active methylene of (I) by molecular oxygen which has unpaired electrons. Momentarily there is produced an intermediate unstable radical (III) which immediately undergoes electronic stabilization to form the conjugated resonance hybrids (IV) and (V)



An oxygen molecule adds to Carbon 13 (IV) or Carbon 9 (V) forming peroxide radicals which extract hydrogen from the active methylene of an adjacent molecule of (I), thereby producing a new radical (III → IV, V) and hydroperoxide. For convenience the radical chain reaction mechanism may be represented by the following oversimplified steps, where RH = (I) and R* = (III) → (IV) and (V)



The primary oxidation product, hydroperoxide, derived from (IV) or (V) is conjugated as shown conclusively by several investigators^{96, 188, 51, 287} and in the early stages accounts for nearly all oxygen absorbed; about 90 per cent of the isolated peroxides are conjugated hydroperoxides. As the oxidation proceeds the conjugated hydroperoxides may undergo further oxidation and form diperoxides by 1,4 addition^{75, 188}, the latter decomposing into products such as aldehydes, acids, and ketones. The hydroperoxides may react (*chemical* oxidation) with double bonds of nearby molecules^{263, 311}, thus accounting at least in part for the rapid loss of unsaturation and corresponding decrease in peroxides during advanced stages of autoxidation. It is evident that a multiplicity of reactions are occurring simultaneously with the primary autoxidative mechanism and producing a mixture of many oxidation products which increase in complexity as the oxidation proceeds. Some decomposition of peroxides must occur even during the "pre-rancid" induction period because the so-called "reverted" odors and flavors precede the detection of typical rancidity. "Reversion," however, appears to be related to the effect of metallic impurities on the autoxidation of linolenic acid principally; the products resulting could be different from those of typical rancidity, although some of them seem to be the same^{311, 312, 45, 281, 298, 156}.

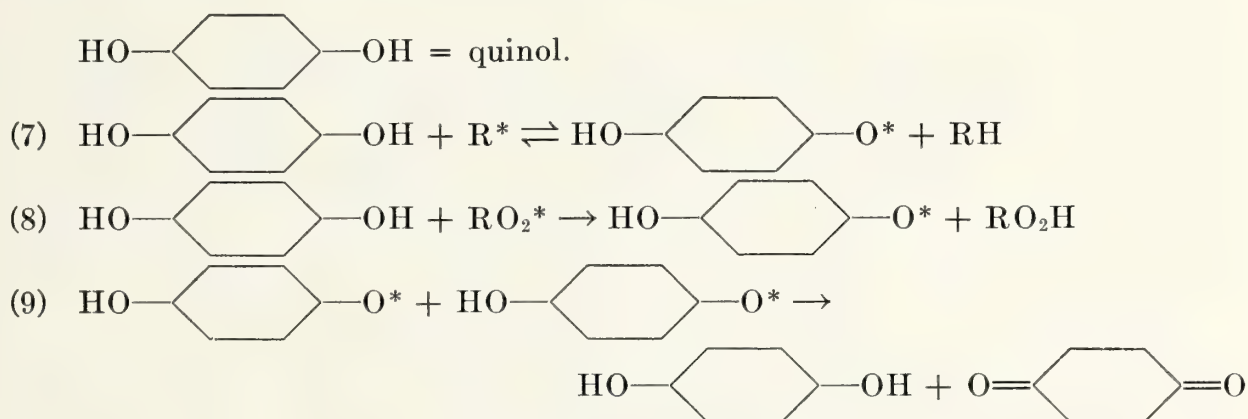
Role of Antioxidants and Catalysts

It is clear that the absorption of heat or light energy would accelerate any of the steps represented in the autoxidation although not necessarily to the same extent. Very little is known about the kinetics of the oxidation steps, although recent work³⁹ has shown a parallellism between rate expressions for reactions between oxygen and ethyl linoleate accelerated by (a) benzoyl peroxide, (b) illumination with ultraviolet radiation, and (c) autoxidation with oxygen in the dark. It was concluded that in either case, the chain propagating and terminating mechanisms were similar but there were divergencies in modes of chain initiation.

Metal salts or oxides, particularly those of the heavy metals, such as

copper and iron, are powerful catalysts and affect the nature of the oxidation products^{63, 107}. Absorbed light energy is known to be a powerful initiator and promotor of free radical mechanisms and to give high quantum yields of product^{13, 4, 35, 34, 58}.

No definition of antioxidant based on mode of action in retarding the primary autoxidation by means of radical or chain termination has been universally accepted, probably because too little is known about the mechanism. Suggestions have been made as to the possible retarding action of quinols, including tocopherols^{62, 101, 211, 116, 210}. The mechanism may be represented somewhat as follows: where RH = linoleic pentadiene system with H as the labile hydrogen, R* = free radical, RO₂* = oxygenated free radical, RO₂H = primary product (hydroperoxide), and



Steps (7) and (8) indicate that the antioxidant furnishes hydrogen atoms to terminate the initiating and propagating mechanism of autoxidation. Owing to the energy required to remove hydrogen from RH to form R*, this step would be sluggish, and if the antioxidant were present at the start before many radicals and chain carriers were produced, it is understandable how only trace amounts could retard greatly the progress of autoxidation even though eventually the antioxidant is destroyed. Evidence that semi-quinone radicals can be formed and are stable enough to exist for appreciable time has been published^{62, 101, 211}. Experimental evidence^{114, 102} has shown that antioxidants are destroyed during the induction period following which there is a rapid increase in the rate of peroxide formation.

It is inadequate to say that an antioxidant is any added substance which retards or decreases the rate of autoxidation, because the rate of oxidation of a substrate containing prooxidant metal salts may be decreased considerably by the addition of certain metal complexing (deactivating) agents. Likewise, since the oxidation is autocatalyzed by hydroperoxides formed, the rate may be decreased by reducing the peroxides with a reagent such as a sulfite.

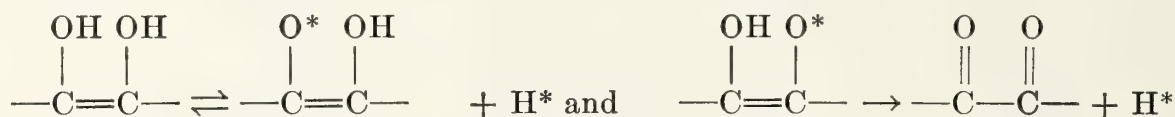
A number of polyhydroxy- or acidic compounds, among which are ascorbic, citric, tartaric, galacturonic, and phosphoric acids bring about a marked

enhancement of the stability of fats containing phenolic antioxidants. These compounds have been referred to as synergists, and the enhancement as a synergistic effect^{241, 118, 49, 200, 50, 266}. In the light of more recent work they appear to have metal deactivation properties in fats and the enhancement can for the most part be explained by the latter function. More will be said about synergists and metal deactivators later in the chapter. The term synergists will be used in these discussions at times without distinction as to mode of action.

Ascorbic acid or its fatty acid monoester^{269, 310} could be considered as a borderline type in that it appears to function as a metal deactivator²¹⁷ and yet has some of the characteristics of a synergist and antioxidant. The

OH OH
| |
—C=C—

similarity between the endiol group —C=C— in ascorbic acid and in catechol, and to a lesser extent in hydroquinone suggests possible similarities in their oxidation-reduction mechanism³³⁵. Possibly the oxidation of ascorbic acid, like hydroquinone, is a univalent free-radical two-stage mechanism,



when used with phenolic antioxidants. If so, it functions in a manner similar to that of phenolic inhibitors in fats, or in other words, it inhibits the oxidation of quinols by furnishing hydrogen atoms to the semiquinone radicals thus regenerating the quinol (the primary fat antioxidant)^{50, 119, 149}. The possible relation of oxidation potentials of antioxidants and synergists to their effectiveness has been suggested¹¹⁶; the most effective antioxidants falling in the potential region between 848 and 484 millivolts. In the above system the oxidation potentials would be in the following order: fat peroxides > quinol > ascorbic acid.

Phosphoric acid also functions as a metal deactivator²¹⁷ and apparently regenerates tocopherol and quinol (or phosphorylated product which acts as an inhibitor) from quinones or semiquinones⁴⁹.

Stability Tests

Most fats and oils when fresh have a slight but characteristic natural flavor. Upon aging exposed to air they begin to lose their fresh flavor and acquire "off" flavors described variously by such terms as stale, musty, beany, fishy, painty, tallowy, etc., until the product becomes rancid. The rancid odor and flavor resemble that of heptylic and nonylic aldehydes. The off-flavors developed prior to the rancid stage, i.e., during the so-called induction period, are often referred to as reverted flavors (or odors)

and undoubtedly are caused by atmospheric oxidation, because during this period hydroperoxides (or peroxides) are slowly being produced and natural antioxidants such as tocopherols are being destroyed as are also vitamin A and carotene. The most highly unsaturated fatty acid components would be the first to start autoxidizing. Animal fats, for example, contain a few tenths of a per cent of acids with four and five double bonds¹⁴². The oxidation of these minor components could easily account for reverted flavors during the pre-rancid stage; the peroxides formed may oxidize certain trace components responsible for the original fresh flavor. By the time the fat or oil is rancid, the inhibitors are destroyed and volatile cleavage products such as aldehydes are being produced. Only a few parts per million are required for detection by sense of smell or taste²². It has been reported that definite rancidity can be detected when $\frac{1}{10}$ of a per cent of fat has undergone oxidative change¹⁸³. Calculations based on peroxide values at the usual rancid point, however, indicate that more nearly 1 per cent of the glycerides would be affected.

Like most subjective tests, organoleptic detection of rancidity suffers a number of disadvantages. Individuals differ in their sensory acuity; even the same person may vary in this respect from time to time. Such tests are not amenable to quantitative expressions that could well be used in following the progress of the oxidation. They are helpful, however, as confirmatory tests in conjunction with chemical tests. Some laboratories have established elaborate "taste-panels" for detection of degree of reversion. Methods and suggestions for conducting such panels have been published^{70, 159, 213, 220, 196}. Panel grading, however, requires a great deal of time and is not well adapted to routine testing.

A number of chemical tests for detection of the rancid point based on colorimetric measurements of aldehydes or carbonyl compounds have been used rather extensively^{168, 157, 146, 259, 177, 100, 254, 282}. The intensity of color or amount of carbonyl taken as the rancid point should be calibrated with the organoleptic test. Since the formation of carbonyls parallels peroxide formation and oxygen uptake during the early stages of autoxidation, it has become a more general practice to use either of the latter measurements to indicate the end of the induction period. This appears not unreasonable because oxygen absorption and peroxides are precursors of the rancid products, and are relatively easy to measure quantitatively. None of these tests for rancidity are reliable for all food products particularly those subjected to unusual conditions. For example, fats being used in deep fat frying do not show a high level of peroxide because the peroxides decompose rapidly at such temperatures. Similarly the decomposition products, i.e., aldehydes, are rapidly removed through volatilization. The state of oxidation in some instances can only be determined by comprehensive analyses of changes

in fatty acid composition, unsaturation, viscosity, and by determination of various oxygenated products.

Methods for detecting rancidity are essential in determining the stability of fats or fats in foods. Stability is defined as the resistance to autoxidation under prescribed conditions of aging and is measured in units of time required for the product to acquire a state of oxidation which correlates with organoleptic detection of rancid odor and flavor. Under usual conditions of storage or merchandising, this time is often too long for practical testing, particularly when antioxidants are being evaluated. Hence it is necessary to employ accelerated conditions of aging. Lea¹⁷⁸ has reviewed the literature on rancidity in edible fats up to 1937 and has discussed the detection of rancidity and stability tests in greater detail.

Stability by Active Oxygen Method. The most widely used method for determining stability of fats and oils is known generally as the Active Oxygen Method (AOM), although it is also frequently called the Swift Stability Test. The essential features of the method were first described by Wheeler³³⁶. A modified and simpler form of the apparatus and technique described by King, Roschen and Irwin¹⁵⁸ has been adopted as standard by many laboratories in this country. Several minor modifications²⁶⁷ have also proved helpful. A uniform flow of washed air is bubbled through the sample of fat contained in an aeration tube, which is immersed in an oil bath maintained at constant temperature, 98 to 99°C, by a boiling water jacket. The progress of autoxidation is followed by periodic organoleptic tests and peroxide determinations. A record of the time is kept from the beginning of the test and for each test period until the sample is definitely rancid. From curves showing a plot of time vs. peroxide accumulation, the time required for the samples to attain the peroxide level established as the "endpoint" can be estimated. Under these conditions rancidity in meat fats can usually be detected organoleptically at a peroxide level of 20 meq. of peroxidic oxygen per kilogram of fat, whereas for vegetable oils and shortenings it is customary to use a peroxide value of 100 meq./kg. as the endpoint. When antioxidants are added to lard, particularly in concentrations of 0.05 per cent or greater, the end of the induction period, as indicated by the inflexion of the time-peroxide curves and also by organoleptic tests, occurs at a considerably higher peroxide level than 20 meq./kg. Hence it has been suggested²¹⁴ that a uniform peroxide value of 100 be taken as the rancid point for lard as well as for vegetable fat. A diagram of an aeration tube, air-distributing system, and a photograph of the assembled apparatus are shown in Figures 8-1, 8-2, and 8-3; typical time-peroxide curves in Figures 8-4 and 8-5.

With minor modifications of the bath and a different type of aeration tube, the apparatus has been adapted to the determination of stability of

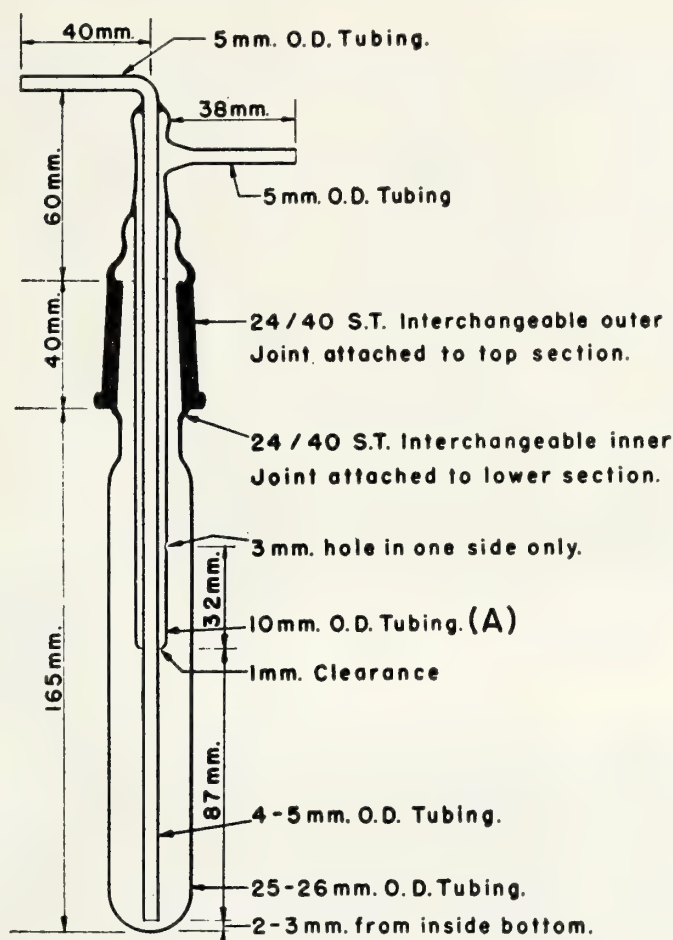


Figure 8-1. Diagram of aeration tube for use in determining stability of fats by the active oxygen method²⁶⁷. (A) Device to prevent foam from being carried out of tube.

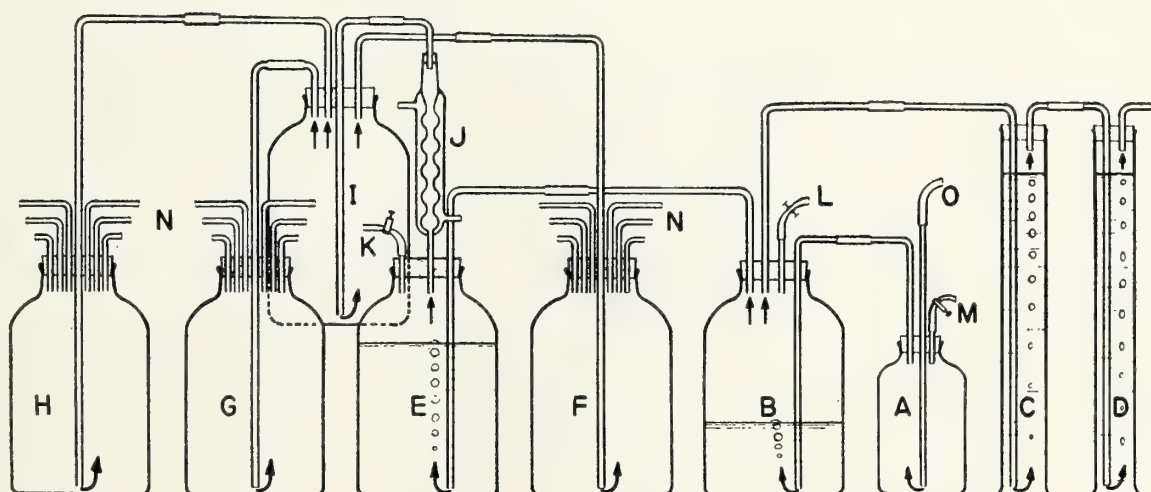


Figure 8-2. Diagram of air purification and distributing system for use in active oxygen method²⁶⁷. (A) device to control pressure of incoming air; (B) bottle containing water for washing air; (C), (D) water columns. Air in space above water in (B) is kept under constant pressure sufficient to by-pass air through (C) and (D) at a steady rate; (E) bottle containing acid dichromate solution. The air in (E) passes through condenser (J) into bottle (I), then into bottles (F), (G), and (H) which distribute the air to the tubes (N), which lead to the aeration tubes. (M) screw clamp to regulate flow of air; (O) connection to source of air pressure; (K), (L) pinchcocks to release pressure when shutting off apparatus.

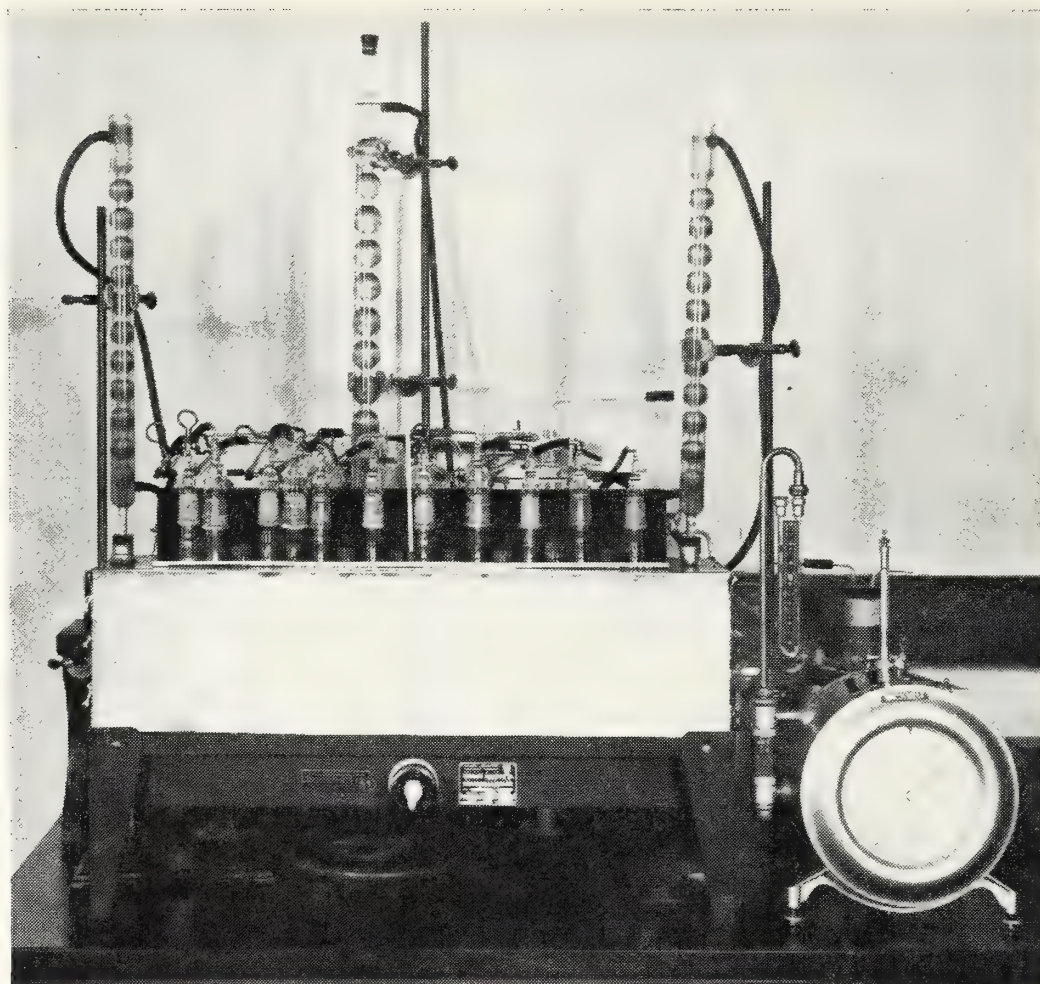


Figure 8-3. Assembled apparatus for determining stability by the active oxygen method.

dry dog meals²³³. The relative concentration of carbonyl compounds in the exit gases from the meal sample being tested were determined colorimetrically by a modification of the procedure of Lappin and Clark¹⁷³. There was a linear relation between formation of carbonyl and peroxide. It seems probable that this modification could be used to determine the stability of many dry feeds and cereal products.

Stability by Oxygen Absorption Methods. Oxygen uptake measurements have been used in many of the earliest studies of autoxidation of oils^{108, 61, 146}, and in evaluation of antioxidants²²¹. The method is still preferred by some workers. Relatively simple apparatus^{125, 106, 314, 154, 328} appears to be adequate. For strict comparison of results between different laboratories, however, standard apparatus and procedure should be adopted. The time required for the sample to absorb a pre-established amount of oxygen under the specific conditions of the test is taken as the stability. This value will vary considerably with different size samples, degree of agitation, temperature, and other factors. One disadvantage of oxygen absorption methods is that organoleptic tests cannot readily be made at intervals during the period of oxygen uptake. An example of the type of apparatus used by Mattill and co-workers is illustrated in Figure 8-6.

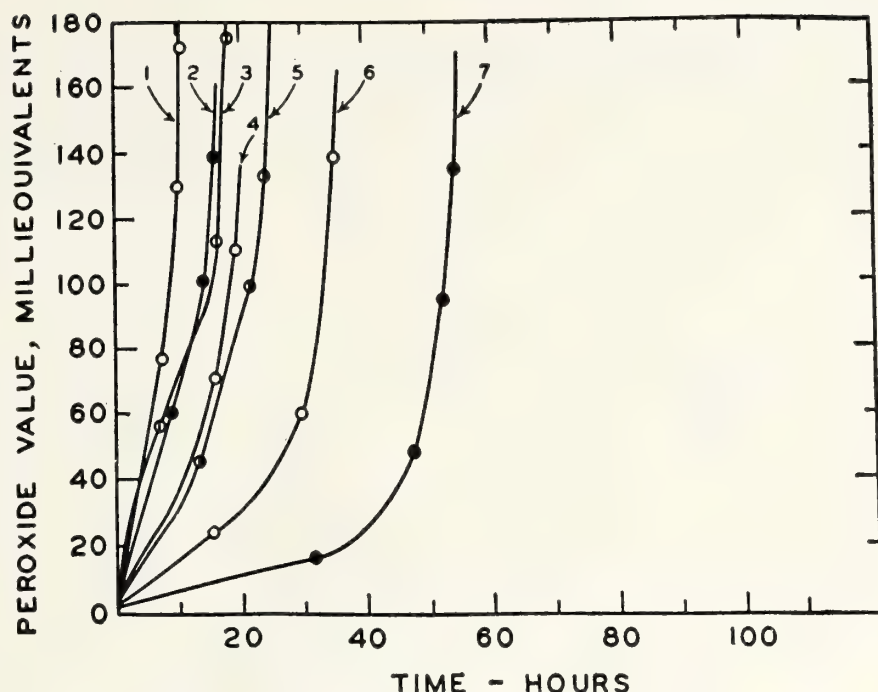


Figure 8-4. Typical time-peroxide curves obtained in determining stability by the active oxygen method²¹⁴. Cottonseed oil containing 0.05% antioxidant. (1) Control; (2) ditertbutyl-*p*-cresol; (3) sesamol; (4) nordihydroguaiaretic acid; (5) norconidendrin; (6) hydroquinone; (7) propyl gallate.

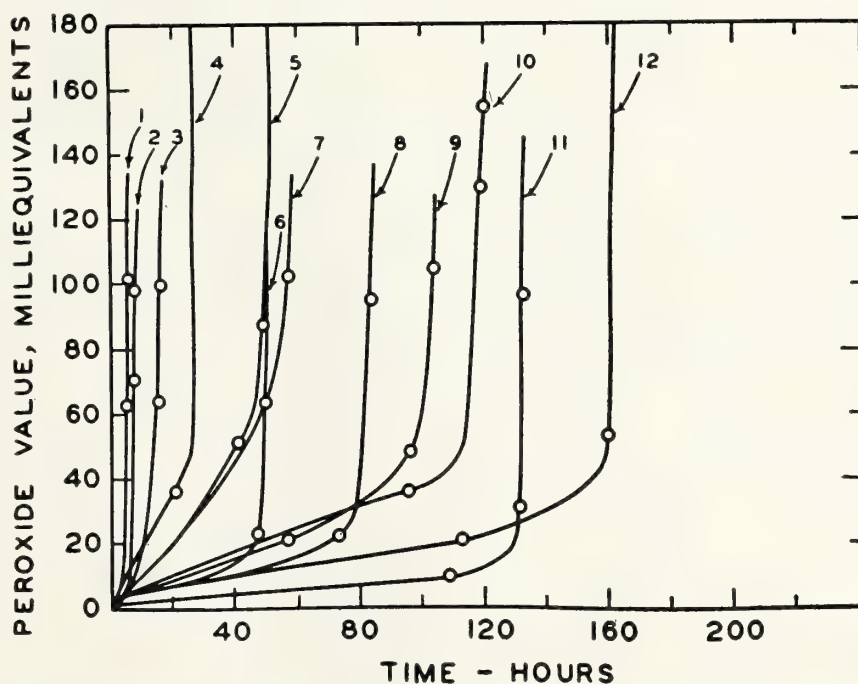


Figure 8-5. Typical time-peroxide curves obtained in determining stability by the active oxygen method²¹⁴. Lard containing 0.05% antioxidant. (1) Control, (2) lecithin; (3) gum guaiac; (4) α -tocopherol; (5) α -tocopherol; (6) ditertbutyl-*p*-cresol; (7) butylated hydroxyanisole; (8) sesamol; (9) norconidendrin, (10) nordihydroguaiaretic acid; (11) hydroquinone; (12) propyl gallate.

Typical oxygen absorption curves on different commercial fats and oils are given in Figure 8-7.

Stability by Oven Incubation Method. Probably the simplest of the commonly used methods for determining stability of fat and some fatty

foods consists of heating the sample in a thermo-regulated oven and testing it at intervals for rancid odor and flavor, or for peroxide content. No standards for this method have been adopted, hence no strict comparisons can be made between results reported by different laboratories. The rather

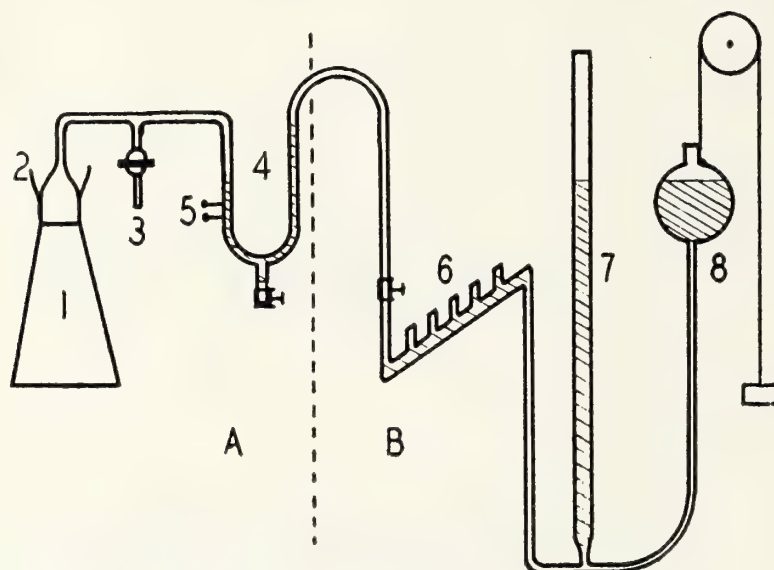


Figure 8-6. Oxygen absorption apparatus¹⁰⁶.

(A) System for determining length of induction period: (1) 250-cc flask with ground-in glass connection; the flask is immersed in a stirred, constant-temperature bath (not shown); (2) tip for mercury seal; (3) side arm for introducing oxygen; (4) Y-manometer; (5) electrical contacts for indicating pressure decrease when mercury is used in manometer.

(B) System for determining pressure changes in (A) at desired intervals: (6) common connections for battery of flasks; (7) 50-cc buret; (8) counterpoised leveling bottle; the fluid (water or Brodie's solution) is shaded in the glass parts and unshaded in the rubber tubing of the manometric system.

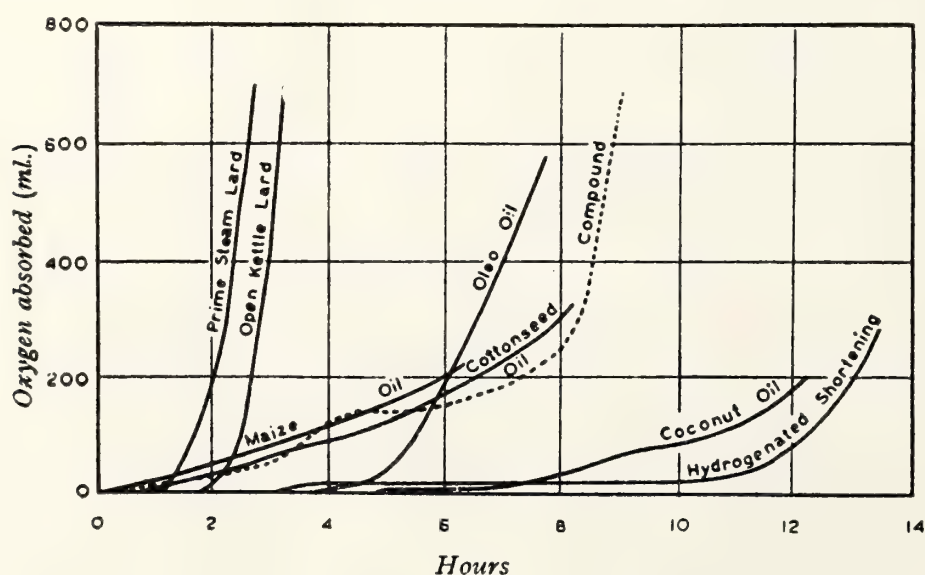


Figure 8-7. Typical time-oxygen absorption curves of commercial oils, lard, and shortening. 200 g samples stirred in oxygen at 95° C³²⁷.

TABLE 8-2. STABILITY OF COTTONSEED AND SOYBEAN OILS CONTAINING ADDED ANTIOXIDANTS*

Antioxidants added	Conc.	Stability			
		AOM		Oven test at 140°F	
		Stabil- ized sample	Control	Stabil- ized sample	Control
	%	hr	hr	days	days
Cottonseed oil† + gum guaiac	0.10	19	15	14	12
+ propyl gallate	0.05	45	12	35	10
+ tocopherols‡	0.05	19	19	12	12
+ NDGA	0.02	14	12	12	10
Soybean oil† + gum guaiac	0.10	17	14	12	9
+ propyl gallate	0.05	54	18	45	14
+ tocopherols	0.05	20	19	12	11
+ NDGA	0.02	26	13	18	12

* Taken from published data¹⁴³.
† Refined and bleached.
‡ Commercial concentrate of natural tocopherols.

general conditions known as the Schaal test are most frequently employed^{252, 130}. A 50-g. portion of fat contained in a 6 to 8 oz. wide-mouth glass jar covered with a watch-glass is heated in a constant temperature air oven at 140 or 145°F. The time required for the sample to become organoleptically rancid is recorded as the stability.

Oven tests at this temperature are also frequently used to determine the stability of fats in baked crackers and piecrust. Details of the preparation and baking of experimental quantities of piecrusts and soda crackers and their stability evaluations have been described^{328, 38, 216, 143, 190}. Typical examples of data obtained by this method are shown in Tables 8-2 and 8-3.

Stability by Storage and Shelf-life Tests. Some fat-containing food preparations, particularly emulsified products, such as salad dressing, mayonnaise, cheese spreads, etc., are not amenable to the accelerated tests described. For these products room or cabinet storage tests, preferably at controlled temperatures, are desirable, the selection of temperature depending on the nature of the product. The detection of rancidity in such products often presents difficulties owing to the influence of flavoring agents and food components other than fats. Taste panel scoring and tests for aldehydes and peroxides are frequently used. It is usually necessary to extract a portion of the fat or oil for determination of aldehyde or peroxide. Since less than a gram of fat is required²⁶⁷, in many instances the extraction can be made simply by grinding a suitable size sample of the food

TABLE 8-3. STABILITY OF LARD CONTAINING ADDED ANTIOXIDANTS AND STABILITY OF CRACKERS MADE WITH STABILIZED LARD*

Antioxidants added	Conc.	Stability		
		Lard		Crackers, oven test at 140°F
		AOM	Oven test at 140°F	
	%	hr	days	days
Lard (control, prime steam)	None	6	7	5
Gum guaiac	0.01	10	9	12
Gum guaiac . . . . .	.05	20	22	30
Gum guaiac . . . . .	.10	24	23	35
Lard (control, prime steam)	None	6	7	8
Propyl gallate	0.01	33	30	11
Propyl gallate . . . . .	.03	50	60	12
Propyl gallate . . . . .	.05	135	124	13
Propyl gallate . . . . .	.10	145	135	14
Lard (control, prime steam)	None	4	4	9
Tocopherols†	0.02	16	15	11
Tocopherols . . . . .	.10	23	18	12
Lard (control, prime steam)	None	5	6	11
NDGA	0.01	18	25	25
NDGA . . . . .	.02	35	32	32
NDGA . . . . .	.05	45	35	35

* Taken from published data¹⁴³.
† Commercial concentrate of natural tocopherols.

product with anhydrous sodium sulfate in a mortar and triturating with several portions of anhydrous peroxide-free ethyl ether, and filtering. The ether is removed by warming under the reduced pressue of a water pump, leaving the oil as a residue.

Storage tests at room temperature have also been employed for meat fats and shortenings, usually as a final confirmatory test after evaluations by other accelerated stability and performance tests have been conducted.

General Discussion of Stability Tests. Owing to the many variables in products and uncontrolled factors in methods for determining stability, it is impossible to make strict comparisons of much of the published data or to give satisfactory quantitative expression for the relative values of anti-oxidants. The principal uses of the accelerated tests are for rapid guides in quality control of the product, and for preliminary “screening” of anti-oxidants and experimental processes.

In much of the published work on antioxidants, it has been common practice to describe the test used, and give stability values for the control fat and for the fat containing a stated concentration of antioxidant; some

workers prefer to express the results relating to the control as unity—the ratio being called the Protection Factor (PF).

Thus

$$\text{PF} = \frac{\text{the stability of the sample containing antioxidant}}{\text{the stability of the control sample}}$$

The latter means of expressing results would have an advantage if the protection factor for a given antioxidant were reproducible even in different samples of the same type of fat. The factor, for example, will generally be much higher in lard of low initial stability than in lard of high initial stability. Care should always be taken to include other pertinent information such as the concentration of the antioxidant and the stability of the controls. Since the protection factors of an antioxidant will also vary depending on the test used, the concentration of antioxidant, and the control substrate, comparisons of different antioxidants at best should be limited to a series where these factors are constant.

The accelerated stability tests have also been used to determine the effect of prooxidants, such as traces of metal salts, and of metal deactivators. Further discussion of metal deactivators and synergists will be given later in the chapter.

In general, there is very poor correlation between the effectiveness of antioxidants in dry whole-fat substrates and the protection afforded foods made with these same stabilized fats. Antioxidants which may stabilize lard against rancidity for over a year at room temperatures, may be almost worthless in ham and many meat products. Therefore, an antioxidant must finally be evaluated in each particular food product.

Antioxidants

Chance observations of retardation of autoxidation were recorded as early as about a century ago. According to Bailey¹⁷, who reviewed the literature up to 1937, one of the earliest references is that of Chevreul⁵⁴ in 1856. Chevreul reported that a film of linseed oil required more time to dry on oak than on poplar or pine wood, and less time on glass than on either of the woods. This retarding effect was attributed later²²³ to the antioxygenic action of tannin in the wood, oak bark being rich in this phenolic substance. The first comprehensive search for substances which would inhibit autoxidation was undertaken during World War I by Moureu and Dufraisse. The incentive was to stabilize acrolein against oxidation and polymerization. Acrolein at that time was considered of importance in chemical warfare. After many empirical tests they found that traces of hydroquinone or pyrogallol maintained the acrolein clear and unaltered, and permitted large-scale production. This observation of the mysterious inhibiting effect

of phenols had a powerful catalytic effect on Moureu and Dufraisse, stirring up boundless enthusiasm and interest, which resulted in prodigious yields. (Bailey (*loc.cit.*) devoted a chapter to a review of their classical work.) In 1922^{222, 221}, they reported the following compounds as retarders of autoxidation and proposed the name "antioxygens": phenol, thymol, guaiacol, eugenol, α - and β -naphthol, hydroquinone, catechol, resorcinol, pyrogallol, gallic acid, tannin, salicyl aldehyde, vanillin, *o*-nitrophenol, and *o*-aminophenol. The autoxidizable substrates in which these compounds were tested included benzaldehyde, acetaldehyde, chloral, propyl aldehyde, acrolein, anisaldehyde, furfural, styrolene, terpentine, linseed oil, walnut oil, and butter. They noted also that the most effective phenols had at least two hydroxyls on the benzene nucleus in ortho- or para-position, and that α -naphthol was much superior to β -naphthol. Later they found²²⁴ also that secondary amines, diamines, and aminophenols were very effective antioxidants, while pyridine, quinoline, amides, and nitroso-bases were of little value. Over 500 different compounds and substances were tested by Moureu, Dufraisse and co-workers in about 100,000 separate oxygen absorption experiments¹⁷. Their theory on mode of action of antioxidants will not be reviewed except to mention that it was based on marked power of selective attraction of antioxidants for activated or oxygenated molecules of autoxidizable substrate, and that antioxidants must reduce peroxides. Within a few years others had made notable studies on the autoxidation of linseed oil and unsaturated organic compounds as affected by catalysts and by antioxidants of the phenolic and aromatic amine type^{270, 271, 295 315, 331, 280}.

Following this phenomenally rapid development in which nearly every conceivable type of compound had already been tested, attention was directed toward possible application of antioxidants in foods to prevent rancidity. Most of the previous work had been done on nonedible products other than fats. Furthermore, little was known of the pharmacology of the many phenolic and amine compounds, although some were suspected of being toxic. Early studies on autoxidation of various vegetable oils and animal fats showed significant differences in induction periods which could not be explained by differences in unsaturation. It was suspected that the presence of natural antioxidants accounted for the longer induction periods. Therefore, extensive efforts were directed toward the isolation and identification of natural antioxidants preferably from edible sources on the reasonable assumption that the addition of such substances to unstable fats and foods might be permitted. Lundberg¹⁸⁶ reviewed the literature on antioxidants up to 1947, and the writer is grateful for help received from his review.

Principal attention will be given to antioxidants which have been investigated thoroughly and are authorized for addition to animal fats, and to

those which have received serious consideration for use in foods. The requirements of an ideal antioxidant have been stated¹⁴³: it should have no harmful physiological effect nor contribute objectionable flavor, odor, or color to the fat or to foods made with the fat; be effective in retarding rancidity and the effectiveness should carry through to foods made with the fat; be sufficiently fat soluble so that it can be incorporated with ease; be readily available and inexpensive.

With appropriate label declarations²⁵⁷ the following substances (preservatives) may be added, in the amounts indicated, to rendered animal fat or a combination of such fat and vegetable fat:

- “(1) Resin guaiac not to exceed $\frac{1}{10}$ of 1 per cent; or
- “(2) Nordihydroguaiaretic acid not to exceed $\frac{1}{100}$ of 1 per cent; or
- “(3) Tocopherols not to exceed $\frac{3}{100}$ of 1 per cent. (A 30 per cent concentration of tocopherols in vegetable oils shall be used when added as a preservative to products designated as “lard” or “rendered pork fat”); or
- “(4) Lecithin: Provided, that nothing in this paragraph shall prevent the use of this substance as an emulsifier as approved by the chief of division; or
- “(5) Citric acid not to exceed $\frac{1}{100}$ of 1 per cent; or
- “(6) Citric acid not to exceed $\frac{5}{1000}$ of 1 per cent, or phosphoric acid not to exceed $\frac{5}{1000}$ of 1 per cent, in combination with not more than $\frac{1}{100}$ per cent of nordihydroguaiaretic acid; or
- “(7) Propyl gallate not to exceed $\frac{1}{100}$ of 1 per cent; or
- “(8) Propyl gallate not to exceed $\frac{1}{100}$ of 1 per cent in combination with not more than $\frac{5}{1000}$ of 1 per cent of citric acid; or
- “(9) Thiodipropionic acid, dilauryl thiodipropionate, distearyl thiodipropionate or combinations thereof in quantities not to exceed $\frac{1}{100}$ of 1 per cent of thiodipropionic acid and $\frac{9}{100}$ of 1 per cent of either dilauryl thiodipropionate or distearyl thiodipropionate or combinations of the two; or
- “(10) Butylated hydroxyanisole (a mixture of 2-tertiarybutyl-4-hydroxyanisole and 3-tertiarybutyl-4-hydroxyanisole) and combinations of butylated hydroxyanisole with nordihydroguaiaretic acid or propyl gallate with or without the addition of citric acid or phosphoric acid, may be added as preservatives to animal fats and shortenings containing animal fats. The quantities used shall not exceed $\frac{2}{100}$ of 1 per cent of butylated hydroxyanisole, or $\frac{1}{100}$ of 1 per cent of nordihydroguaiaretic acid plus $\frac{2}{100}$ of 1 per cent butylated hydroxyanisole or $\frac{1}{100}$ of 1 per cent of propyl gallate plus $\frac{2}{100}$ of 1 per cent of butylated hydroxyanisole. Citric acid or phosphoric acid, not to exceed $\frac{5}{1000}$ of 1 per cent may be added with butylated hydroxyanisole or with the combinations of butylated hydroxyanisole and nordihydroguaiaretic acid or propyl gallate.”

In addition to the above, and with appropriate label declarations mono-

isopropyl citrate may be used as follows²⁰⁷: "Monoisopropyl citrate may be added as a preservative to animal fats and shortenings containing animal fats in an amount not to exceed $\frac{1}{100}$ of 1 per cent."

"When used with other approved fat preservatives, the amount of monoisopropyl citrate may not exceed $\frac{5}{1000}$ of 1 per cent."

Lecithin and Related Substances. Lecithin was probably the first natural substance to receive consideration as an antioxidant for edible fats and oils. The term lecithin has been applied to commercial preparations of mixed phospholipids obtained chiefly as a by-product in the manufacture of soybean oil and corn oil. It is a complex mixture containing lecithin, cephalin, phosphoinositides, sugars, sterols, sterol glucosides, pigments, and antioxidants³³⁷. The antioxidants presumably are minor amounts of tocopherols. Woolley³³⁹ isolated a fraction of phosphoinositides ("soybean lipositol") which had a molecular ratio of 1:1:2 for inositol, phosphoric acid, and fatty acids, and contained no glycerol. Scholfield *et al.*²⁸³ reported a sample of oil-free phospholipids to contain 24 per cent lecithin, 25 per cent cephalin, and 33 per cent phosphoinositides.

The use of commercial lecithin was first proposed by Bollmann in 1923⁴³. It is available in large quantities and at low cost. No question has been raised about the edibility of lecithin and it has been used in food products for many years—in some instances more because of its emulsifying properties. There appears to be some doubt that lecithin is a primary antioxidant; its effect as inhibitor being more like that of a synergist or metal deactivator⁹⁰. The cephalin component of commercial lecithin appears to be responsible for most of the synergistic or inhibiting effect²⁴⁰. The effectiveness of lecithin including its similarity to the effect of phosphoric acid has been described^{241, 15, 238, 244, 265, 268, 313, 322}. Examples of stabilities of fats obtained with added lecithin are in Tables 8-4 and 8-5.

Since phosphoric acid and some of its derivatives appear to be similar in action to that of lecithin, references to some of these compounds are included: phosphoric acid^{15, 80, 117, 238, 261, 176}; phosphorus acid or salts^{260, 67}; esters of phosphoric acid^{84, 82, 274, 231, 197}.

Tocopherols and Related Compounds. Concurrently with the development of lecithin as an inhibitor, Anderegg and Nelson⁵ and Mattill²⁰¹ observed that wheat-germ oil added to experimental diets containing animal fats retarded oxidative rancidification. It was also observed that rancidity was always accompanied by destruction of vitamin E. It was concluded from their work, along with that of Evans and Burr⁹¹ that animal fats contain little if any natural antioxidants whereas wheat-germ oil is relatively rich in such substances. Other evidence of natural antioxygens was soon reported: unsaponifiable fractions from corn-germ oil²⁰³, lettuce lipides²⁴², cottonseed, wheat germ, and palm oils²⁴¹. The close association in these

TABLE 8-4. STABILITY OF LARD, COTTONSEED OIL, AND HYDROGENATED COTTONSEED OIL CONTAINING ADDED ANTIOXIDANTS*

Antioxidant concentration.....	Stability† (AOM)				
	Cottonseed oil		Hydrog. cotton seed oil	Lard	
	0.1%	0.05%	0.01%	0.01%†	0.01%‡
	<i>hr</i>	<i>hr</i>	<i>hr</i>	<i>hr</i>	<i>hr</i>
Control (no antioxidant).....	9.1	9.1	121	4.1	5.0
α-Tocopherol.....	7.6	7.1	107	17.0	18.5
γ-Tocopherol.....	9.0	8.3	135	19.3	30.0
Lecithin.....	10.6	11.3	172	4.8	5.5
α-Conidendrol.....	10.1	13.0	153	25.5	33.1
β-Conidendrol.....	11.4	17.5	174	32.5	44.0
Norconidendrin.....	14.1	22.1	152	25.8	31.0
Nordihydroguaiaretic acid.....	10.0	18.7	120	50.0	62.5
Gum Guaiac.....	6.6	8.5	100	3.4	4.5
Hydroquinone.....	9.3	35.0	128	65.0	70.0
Sesamol.....	8.8	15.5	98	30.8	38.5
Propyl gallate.....	15.8	54.9	172	43.8	47.5
Butylated hydroxyanisole.....	6.6	7.3	108	19.3	31.0
Di-tert-butyl- <i>p</i> -cresol.....	9.4	14.6	118	22.7	26.5

* Taken from published data²¹⁴.
† 20 Meq/kg used as end of induction period.
‡ 100 Meq/kg used as end of induction period.

oils of vitamin E and antioxygenic activity⁷¹, the isolation of vitamin E (α-tocopherol)⁹² and other tocopherols^{82, 299}, and the oxidation inhibiting effect of pure tocopherols²³⁹, led to the conclusion that these oils owe their antioxygenic activity chiefly to these substances. Tocopherols have been reported in many seed oils, fruits, and vegetable and animal tissues. A recent review of their occurrence in natural sources has been published¹⁷². Tocopherol is the only antioxidant that is deposited in adipose tissues of animals to any appreciable extent¹³⁹. It is the principal natural antioxidant of hog fats, being present in about 1 to 3 parts per 100,000⁵⁷, whereas the more common vegetable oils contain from about 30 to 100 parts per 100,000. A great deal of interest was created in the tocopherols because of their nutritional significance as well as antioxygenic activity. They have the further advantage of being readily fat soluble. Along with ascorbic acid or appropriate synergist they offer good protection to fats and oils. The protection, however, does not appear to carry-over well to baked crackers¹⁴³. This is a little surprising in view of the fact that vegetable shortenings of comparable unsaturation and containing tocopherols generally present no serious stability problem in crackers. It suggests that further attention

TABLE 8-5. STABILITY OF LARD CONTAINING BHA AND COMBINATIONS OF BHA WITH SYNERGISTS*

Antioxidant (%)	AOM (hr)	Protection factor
None (control lard).....	8	1.0
BHA 0.01	32	4.0
BHA 0.01 + methionine 0.01	38	4.8
BHA 0.01 + citric acid 0.005	39	4.9
BHA 0.01 + methionine 0.01 + citric acid 0.005...	46	5.8
None (control lard).....	2	1.0
BHA 0.01	16	8.0
BHA 0.01 + H ₃ PO ₄ 0.002.....	21	10.5
BHA 0.01 + triethyl phosphate 0.002.....	20	10.0
BHA 0.01 + ethyl acid phosphate 0.002.....	21	10.5
Lecithin 0.10	4	2.0
BHA 0.01 + lecithin 0.10	26	13.0
BHA 0.01 + lecithin 0.01	21	10.5
BHA 0.01 + citric acid 0.002	36	18.0

* Taken from published data¹⁶⁶; BHA = butylated hydroxyanisole.

should be given to the use of slight hydrogenation to reduce the most highly unsaturated components of lard, together with the addition of tocopherols and synergists. The tocopherols, of course, need not be added as pure compounds. They may be added to meat fats simply by mixing tocopherol-bearing oils or these oils hydrogenated. Riemenschneider *et al.*²⁶⁸ reported the addition of 1 to 10 per cent of certain vegetable oils or shortenings to lard increased the stability from 2 to 5-fold. Magoffin and Bentz¹⁹⁴ reported excellent results from an equal mixture of vegetable shortening and lard for frying potato chips; the chips kept about as well as those fried in vegetable shortening alone (see Table 8-10). Other work on this type of mixture has been published^{264, 9, 182, 320} and patents have been issued^{1, 128, 129, 208, 235}.

The antioxygenic properties of pure tocopherols and concentrates rich in tocopherols have been extensively investigated^{114, 16, 135, 212, 244, 265, 291, 313, 132}, and patents on their use have been granted^{8, 23, 79, 319}. Typical data on their effectiveness are included in Tables 8-2, 8-3, and 8-4.

Compounds related to the tocopherols, such as hydroxy chromans, and hydroxy coumarans have also been reported effective inhibitors of rancidity^{115, 204, 294, 112}.

Gum Guaiac. Gum guaiac, a resinous secretion of a tropical evergreen tree, *Guaiacum officinalis*, indigenous to the West Indies, was first proposed as an antioxidant for fats by Newton and Grettie²³⁴ and described by Grettie¹²⁷. The guaiac resin contains complex phenolic constituents related chemically to guaiacol, guaiaretic acid, and guaiaconic acid. Presumably it owes its antioxygenic properties to one or more of these phenols. The resin also contains significant amounts of inactive insoluble material. The an-

tioxidant may be added to the fat during rendering, the insoluble matter and foreign odor being removed by subsequent filtration and deodorization. Another method is to extract the active constituents of the resin with a solvent such as acetic acid⁷⁴; the filtered extract is then added to the fat at a fairly high temperature and the solvent removed by deodorization. Like other phenolic antioxidants, gum guaiac is more effective in animal fats than in vegetable oils, but unlike many, its protection carries over reasonably well into crackers made with the stabilized fat^{143, 127, 212}. After extensive pharmacological investigations and proof of its innocuous nature was established, gum guaiac was authorized for use in lard and rendered pork fat. This antioxidant was the first substance from a non-food origin permitted as a preservative for lard and rendered pork fats. Data on its effectiveness are included in Tables 8-2, 8-3, and 8-4.

Nordihydroguaiaretic acid (NDGA) and Related Substances. Like gum guaiac, NDGA is a phenolic substance obtained from a natural non-food source. It is obtained by extraction¹¹⁰ from the desert plant, *Larrea divaricata*, one of several species of plants commonly known as creosote bush, which is a common plant in the desert areas of our southwestern states. According to Lundberg *et al.*^{190, 186}, who first described its antioxidant properties, NDGA is only sparingly soluble in fats, about 0.5 per cent at 45°C¹⁸⁹. It may be incorporated into fats by the use of a solvent as described for gum guaiac, or by making a 0.5 per cent solution in hot fat and adding appropriate amounts of the solution to the main portion of fat.

Chemically, NDGA is related to catechol and may be considered as an alkyl substituted catechol. Data on the effectiveness of this compound are included in Tables 8-2, 8-3, 8-4, and 8-6, along with data showing the increased stability when synergists are also added. NDGA is a very effective antioxidant for lard and the protection carries through to some extent to baked crackers (see Table 8-3). Like most phenolic antioxidants, however, it is not particularly effective in cottonseed or soybean oils. In storage tests at room temperature lard stabilized with NDGA remained organoleptically sweet for more than a year¹⁹⁰.

NDGA is physiologically harmless at the low concentrations in which it is used, and authorization has been granted for its addition to lard and rendered pork fat. A public service patent by Lauer¹⁷⁴ covers its use as an antioxidant.

Numerous investigators have evaluated NDGA in different fats and foods by one or more accelerated tests^{9, 24, 31, 30, 199, 266, 214, 169, 180, 326, 278, 277, 276, 59, 163, 33}. In most instances, comparative results were also shown for other phenolic inhibitors and with different synergists or metal deactivators. Compounds related to NDGA in structure have been synthesized by Gisvold¹¹¹.

TABLE 8-6. STABILITY OF LARD CONTAINING ANTIOXIDANTS AND SYNERGISTS*

Antioxidant (%)	Stability AOM	
	Stabilized	Control
	<i>hr</i>	<i>hr</i>
NDGA 0.001	15	6
NDGA 0.001 + citric acid 0.005	26	6
NDGA 0.01	40	4
NDGA 0.01 + citric acid 0.01	119	4
NDGA 0.005	58	7
NDGA 0.005 + citric acid 0.01	67	7
NDGA 0.005 + d-isoascorbyl palmitate 0.005	65	8
Propyl gallate 0.005	40	7
Propyl gallate 0.005 + citric acid 0.01	50	7
Catechol 0.01	44	7
Catechol 0.01 + citric acid 0.01	48	7
Gallic acid 0.005	33	8
Hexyl gallate 0.005†	55	8
Lauryl gallate 0.005†	42	8
Octadecyl gallate 0.005†	55	8

* Taken from published data ^{186, 266}.
† Molecular equivalent of 0.005% gallic acid²¹⁶.

Norconidendrin, and α - and β -conidendrols, are included here because they have some similarity in structure to NDGA. This similarity was pointed out by Fisher *et al.*¹⁰⁴, who first prepared norconidendrin from conidendrin and described its antioxygenic properties. Norconidendrin and the conidendrols presumably are isomeric demethylation products, although the exact relationship to α -norconidendrin and β -norconidendrin (described by Hearon *et al.*^{141, 140} has not been made clear.

Conidendrin, the parent substance, has been isolated from a number of coniferous woods. Its recovery as a by-product from the sulfite waste liquors produced in the pulping of western hemlock would provide large quantities in relatively pure form^{44, 248}.

Norconidendrin and α - and β -conidendrols have been evaluated in a comparative way with a number of other well-known antioxidants for lard, cottonseed oil, and hydrogenated cottonseed oil²¹⁴, for candies¹⁰⁵, and for GR-S polymers¹⁹¹. Its effectiveness in lard was not greatly different from that of NDGA when compared at 0.05 per cent concentration by the AOM; at the more "realistic" level of 0.01 per cent, however, the stability values with NDGA were significantly greater. Of the antioxidants tested propyl gallate appeared to be superior for both cottonseed oil and hydrogenated cottonseed oil, and one of the best for lard. Some of the results are shown in Table 8-4.

Propyl Gallate and Related Substances. Propyl gallate was first proposed as an antioxidant for fats by Sabalitschka and Boehm²⁷⁵. Boehm and Williams^{37, 36} reported it to be highly effective in fats and oils. Lea¹⁷⁵ showed that the methyl and ethyl gallates were also highly effective antioxidants.

These lower esters of gallic acid are readily prepared by ordinary esterification procedures using mineral acid catalyst and are low in cost. They are sparingly soluble in fats and oils and appreciably soluble in water. Higgins and Black¹⁴³ showed that propyl gallate was highly effective in stabilizing lard and also was effective, but to a lesser extent, in cottonseed and soybean oils. The protection, however, did not carry over to baked crackers. Morris and Riemenschneider²¹⁸ prepared higher alkyl gallates to determine the effect of greater fat solubility on the antioxygenic properties. The higher esters were readily soluble in fats and were somewhat more effective than propyl gallate in lard when the antioxidants were added in molecular equivalent amounts, and were also slightly superior in piecrust but neither ester was effective in crackers^{219, 216}. Typical data obtained in the evaluation of propyl gallate and other gallates and related compounds are presented in Tables 8-2, 8-3, 8-4 and 8-6.

In common with most of the phenolic antioxidants, the gallates appear to be most effective when a synergist is also added. Propyl gallate is the only ester of gallic acid which has been given specific authorization for use in meat fats although there is little reason to believe that other alkyl esters would have a different physiological effect. In recent extensive pharmacological tests the evidence indicated that no harmful effects would be produced by ingestion of amounts likely to be encountered in edible fats and oils protected against oxidation^{3, 329}.

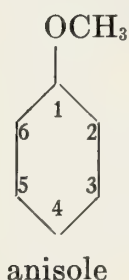
Gallic acid, the compound from which the esters are derived, occurs naturally in teas, and as gallo-tannins and glucosides in nut galls and natural tannins. It is inexpensive and effective for both animal and vegetable fats. The carboxyl group of gallic acid has been reported to act synergistically with the antioxygenic hydroxyls of this compound¹¹⁸. Other workers have supplemented our knowledge of the antioxygenic properties of gallic acid and its esters^{102, 199, 189, 276, 214, 277, 180, 169, 195, 245}. In many references cited, results with antioxidants and synergists were reported. Certain synergistic mixtures have been patented^{136, 137}.

Tannins, a natural source from which gallic acid is obtained by hydrolysis, have been studied as a means of stabilization of fats^{69, 296, 230, 330}. The tannin may be added to the lard at about 70 to 75°C with stirring and then filtered. The tannin appears to act as a scavenger for trace metal impurities²⁹⁶.

Butylated Hydroxyanisole and Related Compounds. The first

publications describing the antioxygenic activity of butylated hydroxyanisole (BHA) in fats in a comprehensive way were those of Kraybill *et al.*^{165, 166, 167}. BHA and certain combinations of BHA with hydroquinone, propyl gallate, acid type synergists (i.e., citric and phosphoric acids), lecithin, methionine, and thiodipropionic acid were very effective in animal fats, and in crackers, pastry and potato chips made with the fat. According to Kraybill *et al.*, commercial BHA consists chiefly of two isomers: 3-tertiarybutyl-4-hydroxyanisole and 2-tertiarybutyl-4-hydroxyanisole. It is readily soluble in fats and oils but nearly insoluble in water, is nontoxic, and imparts no detectable odors to the product.

Rosenwald and Chenicek, who earlier had reported the effectiveness of BHA as an antioxidant for gasoline²⁷², also recently published on the effectiveness in lard of the two isomers of BHA and of a series of derivatives of anisole²⁷³. Their data indicated the importance of the position of the hydroxyl and alkyl substituents in the benzene nucleus in relation to the methoxyl group. If the hydroxyl is adjacent to the methoxyl or in the 3-



position the compound is ineffective, whereas 4-hydroxyanisole has significant activity. If the nucleus is further substituted with alkyl groups, the size and structure of the group as well as the position in which it is substituted has an important influence on antioxygenic activity (see Table 8-7). Thus, the 2-methyl derivative of 4-hydroxyanisole is not as potent as the 3-methyl derivative. The influence of size and structure of the alkyl group is indicated by the finding that 3-tertiarybutyl-4-hydroxyanisole is more potent than the 3-methyl or 3-*n*-butyl derivatives of 4-hydroxyanisole. The 3-tertiarybutyl isomer was 2 to 4 times more effective in a sample of lard than the 2-position isomer and about 2½ times more effective in crackers.

Dugan *et al.*⁷⁶ also observed a significant difference in activity between the two isomers. The 3-tertiarybutyl derivative, however, was only about 1½ times as effective as the 2-isomer in 11 different samples of lard and only slightly better in carry-over in crackers. They found no decided advantage of the 3-isomer over the commercial BHA, a mixture of the two isomers. Compounds with an alkyl substitution adjacent to the hydroxyl were classed as "partially hindered" phenols.

BHA alone and in combination with propyl gallate and citric acid retarded the development of rancidity in corn and peanut oils during deep-

TABLE 8-7. STABILITY OF LARD CONTAINING DERIVATIVES OF HYDROXYANISOLE^{*}

Compound	AOM stability	
	0.005%†	0.02%†
	<i>hr</i>	<i>hr</i>
None (control lard).....	(3)‡	(3)‡
4-Hydroxyanisole.....	7.5	13.5
2-Methyl-4-hydroxyanisole.....	6	17
3-Methyl-4-hydroxyanisole.....	12.5	19
3,5-Dimethyl-4-hydroxyanisole.....	12	15
2,5-Dimethyl-4-hydroxyanisole.....	13	17
2,6-Dimethyl-4-hydroxyanisole.....	<4	<5
3- <i>n</i> -Propyl-4-hydroxyanisole.....	12.5	15.5
3-Allyl-4-hydroxyanisole.....	10	15.5
3-Isopropyl-4-hydroxyanisole.....	10	16
Di-isopropyl-4-hydroxyanisole.....	11	15
3- <i>n</i> -Butyl-4-hydroxyanisole.....	12	17.5
3-Isobutyl-4-hydroxyanisole.....	11.5	16
3- <i>sec</i> -Butyl-4-hydroxyanisole.....	14	20.5
3- <i>t</i> -Butyl-4-hydroxyanisole.....	21	32
2- <i>t</i> -Butyl-4-hydroxyanisole.....	6	13.5
2,5-Di- <i>t</i> -butyl-4-hydroxyanisole.....	12	17
3-Crotyl-4-hydroxyanisole.....	9	15.5
3- β -Methallyl-4-hydroxyanisole.....	10.5	16
3- α -Methallyl-4-hydroxyanisole.....	11	18
3- <i>t</i> -Butyl-5-methyl-4-hydroxyanisole.....	21	35
5- <i>t</i> -Butyl-2-methyl-4-hydroxyanisole.....	18	24
2- <i>t</i> -Butyl-5-methyl-4-hydroxyanisole.....	10	13.5
Hydroquinone.....	40	93.5
Mono- <i>t</i> -butylhydroquinone.....	24	80
2,5-Di- <i>t</i> -butylhydroquinone.....	6	14
<i>t</i> -Butyl-1,4-dimethoxybenzene.....	—	3
3-Hydroxyanisole.....	<4	3
4- <i>t</i> -Butyl-3-hydroxyanisole.....	<4	7
4,6-Di- <i>t</i> -butyl-3-hydroxyanisole.....	<5	7
Resorcinol.....	3	<4
2-Hydroxyanisole (guaiacol).....	<4	<4
3- <i>t</i> -Butyl-2-hydroxyanisole.....	<5	<5
4- <i>t</i> -Butyl-2-hydroxyanisole.....	<5	<5
5- <i>t</i> -Butyl-2-hydroxyanisole.....	<5	<5
5-Methyl-2-hydroxyanisole (creosol).....	—	<4
3- <i>t</i> -Butyl-5-methyl-2-hydroxyanisole.....	<5	7
4- <i>t</i> -Butyl-5-methyl-2-hydroxyanisole.....	<4	7
Catechol.....	25	55
<i>t</i> -Butylcatechol.....	37	65.5

* Taken from published data²⁷³.

† Concentration of compound added.

‡ No compound added.

fat frying, and in foods fried in these oils⁷⁷. It also was effective in delaying rancidity and vitamin A destruction in mixed feeds, such as dry dog meal. The antioxidant has also found application in stabilizing nuts, chicken fat, pastry, and in oils and waxes used to treat papers for food wrappers.

Other workers have substantiated the general effectiveness of BHA and combinations with synergists, such as have been authorized for use in animal fats, and have extended our information on its antioxygenic action^{25, 193, 195, 52, 276, 326, 180, 214, 169, 164, 192}. As a result of the general effectiveness of this substance in different fatty foods and how well it approaches the requirements of an ideal antioxidant, it has become the most widely used antioxidant to date. Typical data obtained in the evaluation of BHA and certain synergistic combinations are included in Tables 8-5, 8-8, 8-9, and 8-10.

Another compound of the "hindered" phenolic type which is receiving careful consideration is 2,6-di-tertiarybutyl-4-methylphenol (2,6-di-tertiarybutyl paracresol). In analogy to butylated hydroxyanisole this compound could be referred to as butylated hydroxy toluene.* This compound probably first received attention for use in gasoline and petroleum products^{300, 301, 304}. Consideration of this material for use in edible fats and oils is relatively recent and very little has been published on it. Moore and Bickford²¹⁴ included this compound in a series of others for comparative evaluation by the AOM in lard, cottonseed oil, and hydrogenated cottonseed oil (see Table 8-4). Likewise, Kring¹⁶⁹ made comparative tests with this compound, alkyl esters of gallic acid, hydroquinone, NDGA, and BHA in the following substrates: lard, peanut oil, soybean oil, codliver oil, and peanut oil containing added vitamin A. The samples were stored at 35°C. All the compounds had noticeable antioxygenic effect but the lower esters of gallic acid seemed to be superior. Citric and phosphoric acid generally enhanced the effect.

Thiodipropionic Acid and its Dialkyl Esters. The only nonphenolic compound, which appears to be a primary antioxidant for fats and oils and which has received authorization for addition to meat fats, is thiodipropionic acid and its lauryl and stearyl esters. The writer was unable to find much published information on the antioxygenic properties of this substance, other than that disclosed in patents^{243, 131} on this and related compounds and several incidental AOM stability tests¹⁶⁶ showing its effect in lard. From the limited published information, the acid, esters, or combination of the two are effective antioxidants in fats and oils and rapidly in-

* Since this manuscript was completed, butylated hydroxytoluene (2,6 di-tertiary butyl paracresol) has also been made permissive, effective June 30, 1954, as a preservative for rendered animal fats and shortenings containing rendered animal fats in amounts not to exceed 1/100 of 1 per cent.

TABLE 8-8. STABILITY OF LARD CONTAINING BUTYLATED HYDROXYANISOLE, OTHER ANTIOXIDANTS, AND SYNERGISTS*

Antioxidant or synergist (%)	AOM (hr)	Protection factor
None (control lard).....	2	1.0
H ₃ PO ₄ 0.005.....	2	1.0
BHA 0.01.....	38	19.0
TDPA 0.01.....	19	9.5
BHA 0.01 + TDPA 0.01.....	81	40.5
TDPA 0.01 + H ₃ PO ₄ 0.005.....	4	2.0
BHA 0.01 + TDPA 0.01 + H ₃ PO ₄ 0.005.....	65	32.5
BHA 0.01 + H ₃ PO ₄ 0.005.....	45	22.5
None (control lard).....	4	1.0
BHA 0.01.....	21	5.3
PG 0.003.....	26	6.5
Hq 0.003.....	27	6.8
BHA 0.01 + PG 0.003 + CA 0.002.....	60	15.0
BHA 0.01 + Hq 0.003 + CA 0.002.....	59	14.8

* Taken from published data¹⁶⁶; BHA = butylated hydroxyanisole; TDPA = thiodipropionic acid; PG = propyl gallate; Hq = hydroquinone; CA = citric acid.

TABLE 8-9. STABILITY OF CRACKERS, PASTRY AND POTATO CHIPS MADE FROM LARD CONTAINING ISOMERS AND MIXTURES OF ISOMERS OF BHA*

Antioxidant†	Schaal oven stability—145°F		
	Crackers‡	Pastry‡	Potato chips‡
	<i>hr</i>	<i>hr</i>	<i>hr</i>
None (control lard).....	161	135	98
3-isomer BHA.....	777	1166	1003
75% 3-isomer, 25% 2-isomer BHA.....	707	1157	924
50% 3-isomer, 50% 2-isomer BHA.....	670	1101	778
25% 3-isomer, 75% 2-isomer BHA.....	697	1115	755
2-isomer BHA.....	633	1107	759
Commercial BHA.....	743	1071	795

* Taken from published data⁷⁶.
† Total antioxidant concentration in each test 0.01%.
‡ Average value from 4 lards.

crease in effectiveness with increase in concentration. Remarkable “synergism” was noted when the acid was added to lard along with BHA¹⁶⁶ (see Table 8-8).

Other Antioxidants. Little useful purpose would be served in attempting to describe numerous published works in which such well-known antioxidants as hydroquinone, catechol, and pyrogallol have been evaluated. In many of the references cited, these compounds have been included for comparative purposes, and examples are also included in some of the tables here for the same reason.

Likewise, there are many substances which have received only superficial examination or very little publicity to date, and others which have not found wide application for unknown reasons. A partial list of these substances is as follows:

1,5-dihydroxynaphthalene¹⁷⁵
 condensation product of polyphenol with a ketone^{175, 209}
 hematoxylin¹⁷⁵
 sesamol^{47, 46}
 caffeic or hydrocaffeic acid^{81, 205}
 2,5-dihydroxyphenyl dimethylcarbinol²⁶
 β -thioketo sulfoxides and sulfones³²¹
 antioxidants of natural spices⁵⁶
 crude source of vitamin B-complex¹³³ and hydroxyanisole¹³⁴
 nuclear-substituted cinnamyl alcohol²
 phenylhendecapentenal and related aldehydes³³⁸
 antioxidants of peel, pulp, or albedo tissue of citrus fruits²⁵⁰
p-amino benzoic acid^{237, 236}
 5-pentadecylresorcinol²⁰
 antioxidants from rice bran^{246, 247, 153}
 antioxidant of osage orange⁶⁰
 derivatives of *p*-phenylenediamine⁶⁴
 derivatives of quinoline¹⁰⁹
 isoeugenol or diisoeugenol¹⁵²
 antioxidants of anise seed¹⁵⁵
 extracts from cereal grain^{66, 151, 229, 72, 184, 227, 249}
 Southern sweet gum²⁰⁶
 alcohol extract of blackstrap molasses²²⁸
 gossypol^{202, 85, 29}
 thyroxine⁷³
 quercetin or dihydroquercetin^{124, 171}

Synergists or Metal Deactivators. The effect of acidic compounds such as ascorbic, citric, tartaric, and phosphoric acids has been mentioned earlier and examples of their enhancing effect on the stability of fats in the presence of primary antioxidants of the phenolic type have been included in tabular data. In the earlier work reported, this enhancing effect was attributed to a synergistic action and the term synergist for these compounds continues to be used, even though their function as metal deactivators has become known, probably because no one has proved conclusively that the effect is entirely attributable to metal deactivation. The suggestion that these compounds function as metal deactivators in fats is not particularly new^{90, 263, 32}. Morris *et al.*²¹⁷, presented evidence which stressed the influence of trace metals and the importance of these acidic compounds in connection with the use of primary antioxidants in the presence of trace metals. Some of their results are reproduced in Tables 8-11, 8-12, 8-13, and 8-14. Ascorbic acid, ascorbyl palmitate and potassium ascorbyl palmitate were

TABLE 8-10. KEEPING QUALITY OF POTATO CHIPS FRIED IN DIFFERENT FATS WITH AND WITHOUT ADDED ANTIOXIDANTS*

Test No.†		Keeping quality of chips at 145°F (days)
1	Lard (control)	5
2	Lard + BHA‡	28
3	Lard + BHA combination§	32
4	Peanut oil (control)	4
5	Peanut oil + BHA	13
6	Peanut oil + BHA combination	14
7	Cottonseed oil (control)	4
8	Cottonseed oil + BHA	6
9	Cottonseed oil + BHA combination	7
10	Vegetable shortening (control)	25-30
11	Vegetable shortening + BHA	47
12	Vegetable shortening + BHA combination	58
13	Lard 50% + peanut oil 50% (control)	14
14	Lard 50% + peanut oil 50% + BHA combination	19
15	Lard 50% + vegetable shortening 50% (control)	20-30
16	Lard 50% + vegetable shortening 50% + BHA	47
17	Lard 50% + vegetable shortening 50% + BHA combination	47
18	Lard 40% + vegetable shortening 60% (control)	42
19	Lard 40% + vegetable shortening 60% + BHA	61
20	Lard 40% + vegetable shortening 60% + BHA combination	70
21	Vegetable shortening (control)	44
22	Vegetable shortening + BHA	65

* Taken from published data¹⁹⁴.

† Tests No. 1-17, laboratory scale fryings; 18-22, commercial fryings.

‡ 0.02% butylated hydroxyanisole added to frying fat.

§ 0.02% butylated hydroxyanisole, 0.006% propyl gallate, and 0.004% citric acid = BHA combination added to frying fat.

most effective in the presence of copper. The latter compound was effective against copper, iron and nickel as was also citric acid. Phosphoric acid offered protection to lard containing copper, iron, and nickel salts. When lauryl gallate was added to lard, however, phosphoric acid was not effective in the presence of iron salts. Compounds other than those listed in the text or tables enhance the stability of fats: ethylene diaminetetraacetic acid²⁸⁵; various amino acids^{185, 59}; polyphosphates³³²; mono and dialkyl (or alkylene) esters of citric acid¹²³.

Trace metals appear to be an important contributing factor in promoting the first (prerancid) oxidative changes which are characterized by "reverted" flavors. The tendency of oils and fats to revert is also associated with the presence of linolenic acid or possibly acids of higher unsaturation. Extensive investigations dealing with the problem of reversion in vegetable

TABLE 8-11. EFFECT OF METALS ON THE STABILITY (AOM) OF LARD²¹⁷

Metals	Conc. (ppm)	Stability (hr)
Control (lard A)	—	7.0
Cu	10.0	0.3
Cu	5.0	0.3
Cu	1.0	0.4
Cu	0.5	0.5
Cu	0.4	0.5
Cu	0.3	0.5
Cu	0.2	0.8
Cu	0.1	3.2
Fe	20.0	0.3
Fe	10.0	0.3
Fe	5	0.3
Fe	3	0.4
Fe	2	0.5
Fe	1	2.0
Ni	2	1.0
Control (lard B)	—	6.0
Ni	4	1.0
Ni	10	1.0
Ni	20	1.0
Sn	10	3.0
Sn	20	1.0

TABLE 8-12. EFFECT OF METALS ON STABILITY OF LARD IN THE PRESENCE OF ANTIOXIDANTS²¹⁷

Antioxidant	AOM stability in presence of				
	0.2 ppm Cu	2.0 ppm Fe	4.0 ppm Ni	20 ppm Sn	No metal
	<i>hr</i>	<i>hr</i>	<i>hr</i>	<i>hr</i>	<i>hr</i>
0.01% lauryl gallate	6.5	0.7	21	—	51
0.02% lauryl gallate	13	—	—	—	—
0.01% ethyl pyrogallol	35	1	72	18	126
0.02% ethyl pyrogallol	54	—	—	—	—
0.01% butylhydroxyanisole	7.5	4.2	15	19	22
0.01% mono- or diethyl ether of ethyl pyrogallol	1	1	3	4.5	12
0.01% ditertiary butyl- <i>p</i> -cresol	5.5	4.7	8.5	12	25
0.02% ditertiary butyl- <i>p</i> -cresol	9.5	—	—	—	39
0.01% β ,3,4-dihydroxy-phenyl alanine . . .	26	0.4	1.2	2	73
0.01% adrenalin	26	8	—	—	83
0.01% phloramine	11	0.7	11	8	35
0.01% methyl phloramine	21	1.5	26	13	54
0.01% JZF*	3.2	0.7	—	—	74

* Chiefly N,N'-diphenyl-*p*-phenylenediamine.

TABLE 8-13. EVALUATION OF SOME SYNERGISTS AS METAL DEACTIVATORS²¹⁷

Synergist	AOM stability in presence of				
	0.2 ppm Cu	0.4 ppm Cu	2.0 ppm Fe	2.0 ppm Ni	No metal
	<i>hr</i>	<i>hr</i>	<i>hr</i>	<i>hr</i>	<i>hr</i>
Control (lard).....	0.8	0.5	0.5	1.0	7
0.01% ascorbic acid.....	10	10	0.5	—	10
0.02% l-ascorbyl palmitate.....	8	—	0.3	—	13
0.024% potassium l-ascorbyl palmitate.....	11	—	8.5	10	14
0.01% tartaric acid.....	4	—	3	6	7
0.016% potassium tartrate.....	0.4	—	0.3	—	6
0.012% K-acid tartrate.....	0.4	—	0.3	—	7
0.01% citric acid.....	2.2	1.7	4.5	3.5	7
0.01% phosphoric acid.....	1.7	—	3.5	4.7	4.7
0.01% sorbitol.....	0.5	—	0.7	—	7
0.01% mannitol.....	0.4	—	0.3	—	3.2
0.01% lactic acid.....	0.4	—	0.5	—	6

TABLE 8-14. EVALUATION OF SYNERGISTS AS METAL DEACTIVATORS IN THE PRESENCE OF 0.01 PER CENT LAURYL GALLATE IN LARD²¹⁷

Synergist	AOM stability in presence of 0.02% lauryl gallate and				
	0.2 ppm Cu	0.4 ppm Cu	2.0 ppm Fe	2.0 ppm Ni	No metal
	<i>hr</i>	<i>hr</i>	<i>hr</i>	<i>hr</i>	<i>hr</i>
None.....	6.5	—	0.7	21	51
0.01% ascorbic acid.....	60	59	0.7	41	63
0.01% l-ascorbyl palmitate.....	67	62	0.3	50	68
0.024% potassium l-ascorbyl palmitate.....	71	—	49	69	74
0.01% citric acid.....	33	26	40	49	56
0.01% phosphoric acid.....	29	—	1.5	31	59

oils, particularly soybean oil, have been under way for a number of years. A recent review of this work has been published by Dutton, Evans and Cowan⁷⁸ with particular emphasis on the present status of the problem, and including a comprehensive bibliography of the pertinent literature on the subject. The subject of reversion in fats and oils is only mentioned here chiefly to point out its close relation to the problem of rancidity. Trace metals are powerful promoters of both types of oxidative deterioration, and metal deactivators play an important part in the practical solution of both problems. In addition to the synergists or metal deactivators already mentioned in connection with rancidity the following compounds were also found effective in counteracting the promoting effect of metals in reversion:

phytic acid^{86, 89}; chelating compounds containing nitrogen as coordinating atom: ethylenediamine tetraacetic acid, oxalohydramic acid, chelidamic acid, and α, α' -amino (acetic acid) propionic acid²⁸⁴; β -stearoxy-, and β -palmitoxy tricarballylic acids²⁸⁵; oxydiacetic and oxydipropionic acids⁸⁷; thiodiacetic and β, β' -thiodipropionic acids, carbomethylmercaptosuccinic acid and its octadecyl ester^{286, 88}.

Antioxidants in Food Products

Much of the early work on retardation of spoilage of fats in food products was concerned with studies of factors which influence enzymatic changes as well as those which influence autoxidation. Similar oxidation products are produced through the action of lipoxidase⁷. The successful application in fats and oils of new and approved antioxidants within the past 10 to 15 years naturally stimulated a great deal of interest in their possible application to many fat-containing foods.

The problem of evaluating antioxidants in such products as meats, dairy products, fish, cereals, etc., is many times more difficult than in simple fats and oils because of the unpredictable influence of food components other than fats and including water and mineral salts. In some products, the fat is only a minor component. Hence the incorporation of antioxidants, satisfactory tests for stability, and the interpretation of results present many difficult problems. Although progress is being made in some products, it is understandable that the results in many cases are inconclusive and in other instances rather disappointing.

Attempts have been made to design stability tests for aqueous-fat systems which may give a better indication of the value of antioxidants for foods than tests conducted on dry fat substrates. In such artificial aqueous-fat substrates, polyphosphates and ascorbic acid were good synergists with phenolic antioxidants^{279, 333, 332, 180}. BHA was one of the best primary antioxidants. In oxygen absorption measurements of methyl linoleate in contact with aqueous phases at controlled pH, the antioxidant efficiency of hydroquinone and NDGA diminished gradually from pH 5.1 to pH 9.2²⁹⁷.

Dairy Products

According to Chilson *et al.*⁵⁵, one of the most difficult problems in market milk is the control of the oxidized flavor which often develops in several days storage at about 35°F. This problem is more troublesome when the cows are on winter feed than when they are on spring pasture. This oxidized flavor development appears to be related to variations in content of copper. Ascorbic acid is rapidly oxidized in the presence of copper and the addition of both to milk hastens the development of off-flavor. The addition of 10 to 20 mg. of propyl gallate per liter of milk retarded this oxidation con-

siderably even in the presence of added copper (0.5 ppm). Esters of gallic acid were also effective in dried whole milk (323) but discoloration may result if appreciable iron salts are present. NDGA also was noticeably effective in delaying this flavor development in whole milk even in the presence of added copper³⁰⁷. The effectiveness of ascorbic acid in whole milk appears to depend on the amount of copper present; if very low in copper, ascorbic acid retards oxidation. Ascorbic acid retards oxidized flavor in stored frozen milk^{11, 6}.

The application of antioxidants to dried milk has given more encouraging results. Phenolic antioxidants were effective particularly when used with synergists and added to milk before drying. Hollender and Tracy¹⁴⁵ reviewed the literature on this subject. Later work showed the following substances to be effective: wheat-germ oil⁵³, ethyl gallate and ascorbic acid^{103, 179}, NDGA and synergists⁴⁸, hydroquinone, cis-isosafroegenol, ascorbic acid²³², tyrosine and its soluble esters, cereal flour and extract⁶⁵.

In butter oil, butter, and cream, the action of antioxidants is somewhat similar to that in lard in that the same antioxidants and synergists appear to be effective in retarding oxidation^{255, 262, 226, 113, 21, 225, 251, 308, 325, 324, 27, 150, 288, 304, 292, 256, 306, 305}. Biacetyl was reported to be prooxygenic in butter and margarine²⁵⁸. It should not be inferred, however, that the use of antioxidants has been found entirely satisfactory. Often their use is accompanied by some reduction in flavor scores and in some cases slight discoloration.

Meat, Fish, and Poultry

The application of antioxidants to fresh meats, fish, and poultry has not proved satisfactory. Some progress is being made, however, and at least measurable beneficial effects have been reported in many studies. Antioxidants were ineffective in preventing rancidity in frozen herring¹⁹; ethyl gallate and ascorbic acid had noticeable preservation effect in storage of frozen salmon fillets^{316, 317}; gallic acid, gum guaiac, ascorbic acid, and NDGA in cottonseed oil when used as a dip were effective to some extent in delaying rancidity of mackerel fillets stored in frozen condition³⁰³. A marked retarding of rancidity of turkey steaks in frozen storage was obtained by use of an aqueous gelatin coating containing either BHA, propyl gallate, or NGDA with citric acid¹⁶⁰; the same antioxidants were effective in retarding rancidity during the cooking and subsequent frozen storage of turkeys¹⁸¹. Bentz *et al.*²⁸ discussed the general application of BHA in combination with propyl gallate and citric acid in stabilizing meats, fish, potato chips, crackers, pastry, butter, nuts, and in waxes used in coatings for foods. Phenolic antioxidants were found helpful in preventing color changes in meats¹⁶².

Fish^{18, 198, 289} and bacon^{293, 161} dipped in aqueous solution of antioxidants and smoked were improved in keeping qualities. Volatile antioxygenic phenolic substances from the wood smoke penetrate the tissue and are about as effective as any means for delaying rancidity in this type of meat product.

Several general concluding statements are justified on the basis of progress made in the stabilization of fats and foods. With reasonable care in processing together with the judicious application of antioxidants and synergists (or metal deactivators), the problem of rancidity in fats, oils, and shortenings is well under control. A great deal more research is required before satisfactory solution to the problem of rancidity and oxidized flavors can be claimed in many fatty foods. Further progress in overcoming the problem in certain foods may depend on studies of the prooxygenic action of trace metals and of the role of synergists or metal deactivators. In some foods it appears that if the prooxygenic action of iron or copper could be effectively blocked, the addition of already known antioxidants would effectively delay rancidity. In this connection, further attention to avoidance of metal contamination in foods is of prime importance.

In view of the important role of linoleic acid (glycerides) in autoxidation

TABLE 8-15. EFFECT OF ANTIOXIDANTS AND SYNERGISTS ON THE OXYGEN ABSORPTION OF METHYL ESTERS OF FAT ACIDS. CONCENTRATION, .01%. TEMPERATURE, 100°C³⁰²

Antioxidant	Me linoleate		Me oleate		Distilled Me esters of lard	
	Stability*	Order of stability	Stability	Order of stability	Stability	Order of stability
	<i>min</i>		<i>hr</i>		<i>hr</i>	
None.....	11	10	2	10	1	10
α-tocopherol.....	41	9	8.5	9	3.5	8
α-tocopherol + C.A.†.....	67	8	35.0	5	8.5	5
α-tocopherol + soya lecithin + d-isoascorbyl palmi- tate‡.....	78	7	36.0	4	4.5	7
NDGA§.....	141	3	43.5	3	9.5	3
NDGA + C.A.....	210	1	135.0	1	31.3	1
Propyl gallate.....	96	5	34.2	6	8.7	4
Propyl gallate + C.A.....	158	2	101.0	2	25.4	2
Benzyhydroquinone.....	85	6	13.0	8	3.0	9
Benzyhydroquinone + C.A.....	126	4	22.5	7	5.2	6

* Time required to absorb 1 g of oxygen per kg.

† Citric acid.

‡ Concentration, .02%.

§ Nordihydroguaiaretic acid.

of fats, perhaps greater emphasis should be placed on evaluation of antioxidants, prooxidants, and metal deactivators in pure methyl linoleate and aqueous emulsions of methyl linoleate. A few examples of effect of antioxidants in pure fatty acid ester substrates are included in Table 8-15.

The most effective antioxidants particularly from the standpoint of carry-over of protection to baked products and fried products such as potato chips are the "partially hindered" phenolics, typified by 3-tertiary-butyl-4-hydroxyanisole. Gallic acid, propyl gallate and possibly other esters of gallic acid are the most effective of the phenols for vegetable oils.

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9. THE ESSENTIAL NUTRIENTS*

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The essential nutrients are those materials which must be supplied by the diet to produce and maintain optimum health. Several species of animals have now been raised to maturity upon diets of essentially known composition and there is reason to believe that practically all of the essential nutrients have been identified. Nearly all of these have been synthesized and the gross effects of the corresponding deficiency diseases have been documented. On the other hand, the absolute amounts required under varied conditions and by different species, the long term effects of slight deficiencies or excesses and the biochemical mechanisms involved, are still being actively investigated. Few statements in this field can be accepted as definite and the reader should be duly cautious. The original expectation that once the various factors were identified and requirements determined it would be relatively simple to determine which diets were adequate or inadequate, is still far in the future. We now recognize numerous interrelationships between nutrients, variation between individuals of the same species, great differences among species, intestinal synthesis of variable amount depending upon the diet and sanitary conditions, adaptation to diets, and there are undoubtedly other factors influencing requirements¹. When one considers the permutations possible among the forty odd nutrients, the possibilities and difficulties become clear.

Nutritional requirements must be considered as approximations based upon the average individual and perhaps under average conditions as we understand them today. They are much less applicable to the individual. Recommended allowances as distinct from requirements are always set somewhat above estimated requirements to provide a margin of safety.

* See Section in Appendix on Recommended Dietary Allowances; also Chapters 12, 15, 17, 18, 19 and 20.

CALORIES

Carbohydrates and fats constitute the principal sources of energy although amino acids not deposited as protein in the body also are oxidized to supply calories. The total calories supplied by a food are usually calculated as 4 calories per gram of carbohydrate or protein and 9 calories per gram of fat. These values are based upon the average values obtained by combustion in a calorimeter corrected for a fraction which is undigested. The energy content of nitrogenous excretory products is also subtracted from the energy content of the protein. In animal feeding the term "total digestible nutrients" is often used which is simply the sum of the protein, fiber, and other carbohydrate plus 2.25 times the amount of fat. A great deal of study has been made of the energy supplied by various foods, but many workers fail to realize the variation in animals and the mutual effects of one food upon another which can seldom be measured. The amount of fiber in the diet may affect the digestibility of the fat, protein and fiber itself. Hence, values such as the 4, 4, 9 calories per gram must be considered as average values, applicable in general, but possibly in considerable error when applied under a particular situation.

Carbohydrates are ordinarily the cheapest form of calories and supply the bulk of the calories. Whether carbohydrates are absolutely essential in the diet is not quite clear but diets very high in fat generally produce ketosis. Similarly, acidosis and ketosis result during faulty carbohydrate oxidation in diabetes, and excess fat oxidation in starvation. Diets without any fat produce fatty acid deficiency as discussed later. In addition, it has been shown that dairy cows require a certain amount of fat in the diet for satisfactory production². Fat seems to be essential for the formation of palatable diet for human beings and probably for other species. Fat may also slow down digestion to a degree and give satiety value to the diet. Hard working men with calorie requirements of the order of 5 to 6,000 calories per day, lumberjacks, for example, require fat in the diet to reach this level of calorie intake without overloading the capacity of the stomach.

The total calorie requirements³ may be considered as the sum of the calories required for basal metabolism (calorie required during complete rest), plus calories required for work plus calories required for digestion and metabolism of food (specific dynamic action) plus calories required to maintain the temperature. In general the basal metabolism is a function of the "physiological mass" and this is found to be proportional to weight^{0.73} in mature species of all kinds. Specific dynamic action is often calculated as 10 per cent of the total calorie intake. The number of calories required for work and temperature control of course depends upon the kind and amount of work done and the environmental conditions. Animals that are growing, fattening or producing milk, wool, young, etc., require additional energy

for these purposes. Efficiency of production may vary considerably. Whereas many of the older feeding standards allowed energy in proportion to weight, the trend is now toward the use of weight^{0.73} as the baseline⁴. A 2000 pound cow does not consume twice as much feed as a 1000 pound cow other factors being equal.

Excess food ingestion leading to obesity is now considered the major nutritional disease in the United States. Obesity is related to earlier incidence of many degenerative diseases—cancer, arteriosclerosis and hypertension. Practical methods of treatment remain obscure⁵.

PROTEINS AND AMINO ACIDS

The proteins of the body tissues are continually broken down and replaced. Approximately 22 amino acids are required for protein synthesis and 8 or 10 of these, the essential amino acids, cannot be synthesized rapidly enough to meet body requirements. These must be supplied by the diet. Thus protein is required to provide the nitrogenous materials for synthesis of the nonessential amino acids and certain specialized materials and to provide the essential amino acids.

As indicated in Table 9-1, the essential amino acids vary somewhat with the species. Arginine is synthesized to a limited extent by the rat but not by the chick. Glutamic acid and glycine occupy a similar position in chick nutrition. In adult man none of these three seems to be required. Other species have been little studied. Ruminants have great synthetic ability in the

TABLE 9-1. REQUIREMENTS OF ESSENTIAL AMINO ACIDS*

Amino acids	Growing rat, % of diet	Growing chick, % of diet	Adult man, g/day
Arginine.....	0.2	1.2	0
Histidine.....	.4	0.15	0
Lysine.....	1.0	.9	0.80
Tryptophan.....	0.2	.2	.25
Methionine.....	.5	.45	1.10†
Phenylalanine.....	.7	.9	1.10‡
Leucine.....	.8	1.4	1.10
Isoleucine.....	.5	0.6	0.7
Valine.....	.7	.8	.8
Threonine.....	.5	.6	.5
Glycine.....	0	1.0	0
Glutamic acid.....	—	+	—
Total Protein.....	20	20	70§

* Adapted from Almquist, H. J., "Proteins and Amino Acids in Animal Nutrition," 3rd Ed., U. S. Industrial Chemicals Co., New York.

† Includes quota for synthesis of cystine.

‡ Includes quota for synthesis of tyrosine.

§ Recommended allowance.

rumen and the use of urea as a practical nitrogen supplement is well established⁶.

The nutritive value of a protein depends largely upon its amino acid composition and estimation of the essential amino acid content provides a method of assaying the nutritive value⁷. Since the body has limited storage ability of amino acids as such and all are required simultaneously for protein synthesis, maximum utilization is obtained only when all are provided at the same feeding. Proteins lacking in different amino acids will be poor when fed alone but may provide an excellent protein mixture if they mutually supplement the deficiencies of each other⁸.

The total protein requirement depends primarily upon (a) the nutritional value of the protein fed and (b) the function to be fulfilled, i.e., growth, maintenance, lactation, etc. They are high when tissue is being rapidly formed and relatively low in the adult. Work does not raise protein needs provided the caloric need is fulfilled. The minimum protein needs are not well defined in relation to different kinds of protein. They are, however, proportional to the basal metabolic rate in various species and vary with body weight to the 0.73 power⁴.

Injury of all kinds induces the so-called "alarm reaction" which is characterized by the breakdown of body protein and the excretion of large amounts of nitrogen in the urine. Feeding high levels of protein does not reverse this effect. In the recovery phase these tissue losses must be replaced and the protein requirement is high. Severe protein depletion impairs the formation of antibodies which are proteins and may lower resistance to infections⁹. Depletion also lowers the level of the plasma proteins and since these are effective in maintaining the osmotic pressure of the plasma loss of fluid to the tissues and edema may result. Concurrent changes in blood pressure, kidney function, etc., probably account for the failure to find close correlations with edema occurrence and the level of the plasma proteins. Edema is an important problem in all starving populations^{10, 11}.

Protein deficiency in infants probably modified by vitamin and mineral deficiencies is now considered as one of the most important world health problems. It is known as kwashiorkor, infantile pellagra, multiple deficiency syndrome, etc., in various parts of the world and is characterized chiefly by edema, liver dysfunction, emaciation and various skin changes. It is most severe in the post-weaning period when satisfactory foods are not available to replace breast milk¹².

The composition of most plant proteins is less satisfactory than most proteins of animal origin. Lysine is probably the most limiting amino acid in most cereals⁷ and methionine supplementation of vegetable diets for chicks is required. The possibilities of supplementing vegetable diets with amino acids of commercial origin and thus avoiding the need of animal protein supplements would appear to be a development of the near future.

ESSENTIAL FATTY ACIDS

Feeding diets extremely low in fat to rats decreases growth, causes the development of scaly tails and kidney lesions. The administration of small amounts of linoleic, linolenic or arachidonic acid prevent the development of the lesions¹³. No other species has been studied to any extent. It would appear unlikely that deficiencies of the essential fatty acids would occur under ordinary conditions.

THE VITAMINS

The vitamins are defined as organic materials which must be supplied in small amount by the diet other than the essential amino acids and essential fatty acids. Small is a relative word and the definition somewhat arbitrary since in some cases several active forms are known. It is important to note that no similarity of structure or function is implied by the word vitamin or among the vitamins grouped upon the basis of solubility as fat and water soluble nor among members classified as part of the B complex.

Fat-Soluble Vitamins

Two common features may be noted among the fat-soluble vitamins. First that their absorption is dependent to a large extent upon a normal absorption of fat from the diet. Deficiencies are more likely in those diseases where fat metabolism is abnormal—sprue, celiac disease, gall bladder disease, etc., and larger amounts must be supplied. The amount and kind of fat in the diet may also be of importance. Mineral oil given with the vitamins may prevent absorption. Secondly, three of the vitamins, A, E, and K, contain the carbon skeleton of phytyl alcohol, a constituent of chlorophyll. It is suggested by some that the sterol nucleus of the vitamin D precursors might also have this origin. The significance of this common feature is unknown.

Vitamin A. Vitamin A is a highly unsaturated alcohol rather easily oxidized to inactive materials. The vitamin occurs only in animal materials, principally the liver where it is stored. Until recent years fish liver oils were the principal source and certain fish store huge amounts, up to one-third the weight of the liver. The origin and function of such abundant supplies is unknown. Within recent years, synthetic methods have been developed upon a commercial scale.

The vitamin occurs principally as the ester of the common fatty acids. The corresponding aldehyde, acid and certain other derivatives are also active. Plant materials contain no vitamin A but a few of the common carotenoid pigments serve as precursors and are changed into vitamin A in the body. The intestinal mucosa is probably the principal site of this transformation¹⁴. Usually β -carotene is only about one-half as active as vitamin A on a weight basis. The absolute activity depends upon many

factors. Antioxidants such as vitamin E protect the carotene, free fatty acids destroy it. The ability to absorb carotene is influenced by the amount of fat in the diet, the source of the carotene, liver function, and probably by the need of the body. By definition, one unit of vitamin A activity is equal to 0.3 μg of vitamin A alcohol or 0.6 μg of beta-carotene. Such definition does not obviate the fact that these two units are not equal under many conditions. It has been suggested that under practical conditions one might accept a unit of activity from carotene as one-third to one-fourth as active as vitamin A.

The symptoms of vitamin A deficiency are principally (a) night blindness related to the function in the visual cycle, (b) failure of bone growth in young animals, and (c) metamorphosis of the normal secreting epithelium of the nose, throat, urogenital tract, eye, etc., into a dry squamous-type epithelium. The function of vitamin A in the eye has been quite well defined by Wald¹⁵. The pigment rhodopsin occurring in the rods is a vitamin A protein complex which is disrupted by light to yield vitamin A aldehyde and protein. This initiates the nerve impulse. The aldehyde is then reduced to the alcohol and may combine with the protein. In deficiency the formation of rhodopsin is diminished and vision in dim light is impaired.

The function in the bones is not well defined. Longitudinal bone growth ceases early in the deficiency. Continued growth of soft tissue leads to pressure in those areas where nerve tissue is surrounded by bone and paralysis results. Appositional bone growth, on the sides of the bones, apparently continues^{16, 17}. This has led to dispute as to whether or not vitamin A deficiency inhibits or increases bone growth. Vitamin A toxicity is easily produced experimentally and is not uncommon clinically because of overzealous or uninformed parents. It is characterized by increased changes associated with bone growth. Areas where bone is normally reabsorbed become fragile and fracture.

The changes observed in the epithelium yield a dry squamous covering which is less resistant to bacterial invasion. Secondary infections are a common cause of death. This led to the early designation of the vitamin as an "anti-infection vitamin." There is no evidence, however, that the vitamin has a direct role in combating common infections. There is recent evidence from tissue culture that the vitamin plays a direct role on the parent cells of the epithelium and determines which kind of epithelium will be produced, excess vitamin preventing the development of normal keratinized skin¹⁸.

The evidence is quite convincing that in practically all species studied the minimum requirement for vitamin A is about 20 units of vitamin A itself or 40 units supplied as carotene per kilogram of body weight¹⁹. This would mean that the minimum need of an average man would be about 1400 units of vitamin A or 2800 units of carotene. In many diets the vitamin A

intake is rather low and the principal sources are the plant materials which supply carotene. Recommended allowances are 5000 units of vitamin A activity per day in the United States for adults or as much as double this amount in English standards.

The chief sources of vitamin A are liver and dairy products. Carotene is supplied by yellow vegetables and fruits such as carrots, squash, sweet potato, etc., and the green leafy vegetables. The amount of carotene in such materials is relatively great and the allowance is rather easily supplied provided some of the materials are included in the diet.

Vitamin D. Vitamin D is formed in the skin or artificially by the irradiation of specific sterol precursors with ultraviolet light. The two active compounds of principal interest are vitamin D₂ and vitamin D₃ formed from ergosterol and 7-dehydrocholesterol, respectively. Other active compounds are known and they vary in activity. Vitamin D₂ and D₃ are equally active for the rat and possibly for the human but D₃, the naturally occurring form, is more active for the chick.

The function of vitamin D is not well defined. In its absence rickets develops. This is characterized by a continued proliferation of matrix at the long ends of the bone but there is a failure of the matrix to calcify. Pressure causes the soft matrix to expand and enlarged, misshapen joints are formed. Continued excretion of calcium results in softening of other bones and they become malformed. Bowed legs is the most common symptom. The general muscle tone is poor and enlarged, sagging abdomen is seen. It is generally agreed that calcium absorption is poor but no absolute evidence as to whether or not this is due to a direct action of vitamin D is at hand nor is there evidence as to the mechanism involved in the regulation of calcium absorption. Some authors have suggested that the effects on calcium are secondary to those on phosphorus absorption, that kidney excretion is involved, that there are direct effects upon bone calcification. Most data suggest a primary effect upon calcium absorption²⁰.

In some species, particularly the rat, the vitamin D requirement is primarily dependent upon the ratio of calcium and phosphorus in the diet and the amounts. They have no vitamin D requirement when the ratio is approximately 1 and sufficient calcium is provided. In chicks, human beings, pigs, and undoubtedly other species, rickets develop even when the calcium and phosphorus intakes are satisfactory. Relatively little evidence is available as to the effects in these species of the Ca/P ratio on the vitamin D requirement.

Relatively few foods contain vitamin D. Some occurs in milk and butter and liver may be fairly rich. Certain fish liver oils are potent sources. Naturally, therefore, most animals depend upon exposure to sunlight for their source of the vitamin rather than the diet, the 7-dehydrocholesterol of

the skin and skin secretions being transformed into the vitamin. Under modern conditions of life where exposure to sunlight is limited by housing, smoke, clothing, etc., dietary sources are essential for children. Vitamin D enriched milk and some other foods are satisfactory but they are not consumed widely enough to be considered as completely effective as public health measures²¹. In modern poultry husbandry, sources of vitamin D are essential. With other species, vitamin D must be given consideration if the exposure to sunlight is severely limited over long periods of time. However, relatively little exposure suffices and the vitamin is stored in the liver for considerable periods.

The requirement for poultry is well established. Less adequate data are available on most other species. In children 400 units per day is considered optimum and more may not only be no more satisfactory, but less so. Large amounts produce vitamin D toxicity. The requirements for adult species are little known. Definite deficiency in adult man has perhaps only been definitely established in pregnant and lactating women in countries where the calcium intake is low and perhaps in nuns and others who are closely protected from sunlight exposure.

Vitamin E. Vitamin E was first shown to be essential for reproduction in rats. In its absence the fetus was resorbed in the pregnant females and males became sterile. Numerous other symptoms have since been described including encephalomalacia in chicks, muscular paralysis and dystrophy in rabbits, dogs and other species²², heart failure in cattle, exudative diathesis in chicks, etc. Deficiency symptoms in humans are not known.

Numerous compounds of related chemical structure have antisterility action when tested in rats fed vitamin E free diets. Recently it has been shown that even such oxidation-reduction compounds as methylene blue prevent many but probably not all of the symptoms of vitamin E deficiency in chicks^{22a}. Vitamin E is a potent antioxidant and it has been suggested that the function of vitamin E is to serve in this function in the body. Tissues from vitamin E deficient animals have high oxidation rates when tested *in vitro*. Mechanisms are unknown.

The best sources of vitamin E are certain vegetable oils such as wheat germ oil but it is likely that many substances occurring naturally may at least partially replace vitamin E. Under practical conditions vitamin E deficiency is probably rare although it occurs in chicks and may occur in cattle²³.

Vitamin K. Vitamin K is required for the normal formation of prothrombin, a precursor of thrombin, which forms the blood clot. Vitamin K deficiency is manifest by failure of the blood to clot and severely deficient animals may bleed to death^{23a}. Mechanisms of vitamin K action are unknown but since the vitamin is not a part of prothrombin it must be concerned in its synthesis.

Vitamin K is required in the diets of chicks but is synthesized by the gastrointestinal flora of the rat, dog, probably the human. Vitamin K deficiency occurs in human beings under two conditions: (1) in liver disease where fat absorption is impaired and there is consequently inefficient absorption of the fat-soluble vitamins, and (2) in the newborn infant. Operations for gall bladder disease, for example, were very serious because of hemorrhage prior to the isolation of vitamin K. Large numbers of infants die of hemorrhage shortly after birth due to trauma suffered at birth. Apparently in infants the level of vitamin K is not sufficient until the gastrointestinal flora becomes established. Both conditions are corrected by vitamin administration and dosage of the mother prior to delivery will protect the infant.

While two natural vitamin K's are known, numerous synthetic compounds have activity. The most active, even more active than the vitamin K₁ or K₂, is 2-Me,1-4-napthoquinone. Doses of the order of 1 microgram are sufficient to protect infants and raise their prothrombin levels to normal.

A disease in cattle caused by the feeding of spoiled sweet clover hay is due to the presence of dicoumarol (3,3'-methylene bis (4-hydroxycoumarin)). This acts as an antivitamin and produces a vitamin K deficiency which is reversible with vitamin K₁ but not with 2-Me,1-4 naphthoquinone²⁴. Dicoumarol finds clinical use as an anticoagulant in the prevention of thrombus formation. Recent reports indicate the occurrence of vitamin K deficiency in poultry possibly induced by the feeding of antibiotics.

Water-Soluble Vitamins

Vitamin C. In so far as is known, the guinea pig, the primate apes and monkeys, and man, are the only species which require vitamin C in the diet. Other species synthesize the vitamin within the body²⁵.

The disease is characterized primarily by faulty formation of the "cement substance" between cells and the faulty formation of collagen. The fragile capillary walls which result allow bleeding upon slight trauma. This is particularly evident in the gums. Bone formation is impaired. The joints become sore and painful, the teeth loose. Ascorbic acid is highly specific although some isomers apparently have some slight activity.

Ascorbic acid is easily oxidized, particularly at high temperature and is the vitamin most readily lost during cooking. Storage of food is usually associated with vitamin C losses except under modern methods of freezing and canning. Scurvy is usually seen in children not given the vitamin, orange juice or other appropriate sources. Milk is not a reliable source. In the past scurvy was serious on voyages and campaigns where dried rations were necessary.

The function of vitamin C is little understood. In scurvy the amino acids tryrosine and phenylalanine are incompletely oxidized and the oxidation

product, dihydroxyphenylalanine occurs in the urine²⁶. The vitamin also appears to be necessary for the transformation of folic acid into citrovorum factor (see below). This is the probable cause of the anemia seen in scurvy²⁷.

The minimum requirement of vitamin C is about 10 mg per day²⁸. This will prevent scurvy in the adult. However, there is considerable disagreement as to whether much higher levels are beneficial. Recommended intakes thus vary from 30 mg per day in England to 70 mg per day in the United States (see p. 948). The latter amount is required to maintain a blood level similar to that found in animals which synthesize their own vitamin C. Blood levels clearly reflect the vitamin C intake. The white cells of the plasma maintain their vitamin C content after all vitamin C has disappeared from the plasma. When the level in the white cells begins to fall scurvy is imminent.

The better sources of the vitamin are the citrus fruits, tomatoes, cabbage, green peppers, etc. Although the vitamin content of materials such as potatoes is not high these are often consumed in sufficient amounts to be the chief protection against scurvy. Nearly all fresh vegetables and fruits contain significant amounts while cereals and most meats are not good sources.

The B Complex Vitamins

The classification of certain vitamins as members of the B complex reflects the historical accident that they were present in the chief sources, liver and yeast, of the original vitamin B and all are water soluble. Whether vitamin B₁₂ should be so classified is debatable. With the possible exception of the vitamin B₁₂ all members of the B complex are probably required for plant or animal life. Species vary however in that some are able to synthesize certain of the vitamins, in the gastrointestinal tract or otherwise, while others are not.

Thiamine. A deficiency of thiamine produces the disease beriberi in human beings and a similar polyneuritis in experimental animals. Animals suffering from the acute deficiency may succumb without showing typical symptoms. The deficiency has been primarily associated with groups eating polished rice as in the Far East and in alcoholics. Fortification of white bread and rice with thiamine provides an effective means of combating beriberi²⁹. In animals the deficiency was of particular importance in fox raising. An enzyme which destroys thiamine, thiaminase, occurs in various fresh water fish and diets containing large amounts of fresh fish may produce the paralysis known as Chastek paralysis³⁰. A condition in cattle produced by the consumption of the bracken fern, appears to be a similarly induced deficiency³¹. Ordinarily, the ruminants produce sufficient thiamin in the rumen by bacterial growth so as to make them independent of the dietary supply.

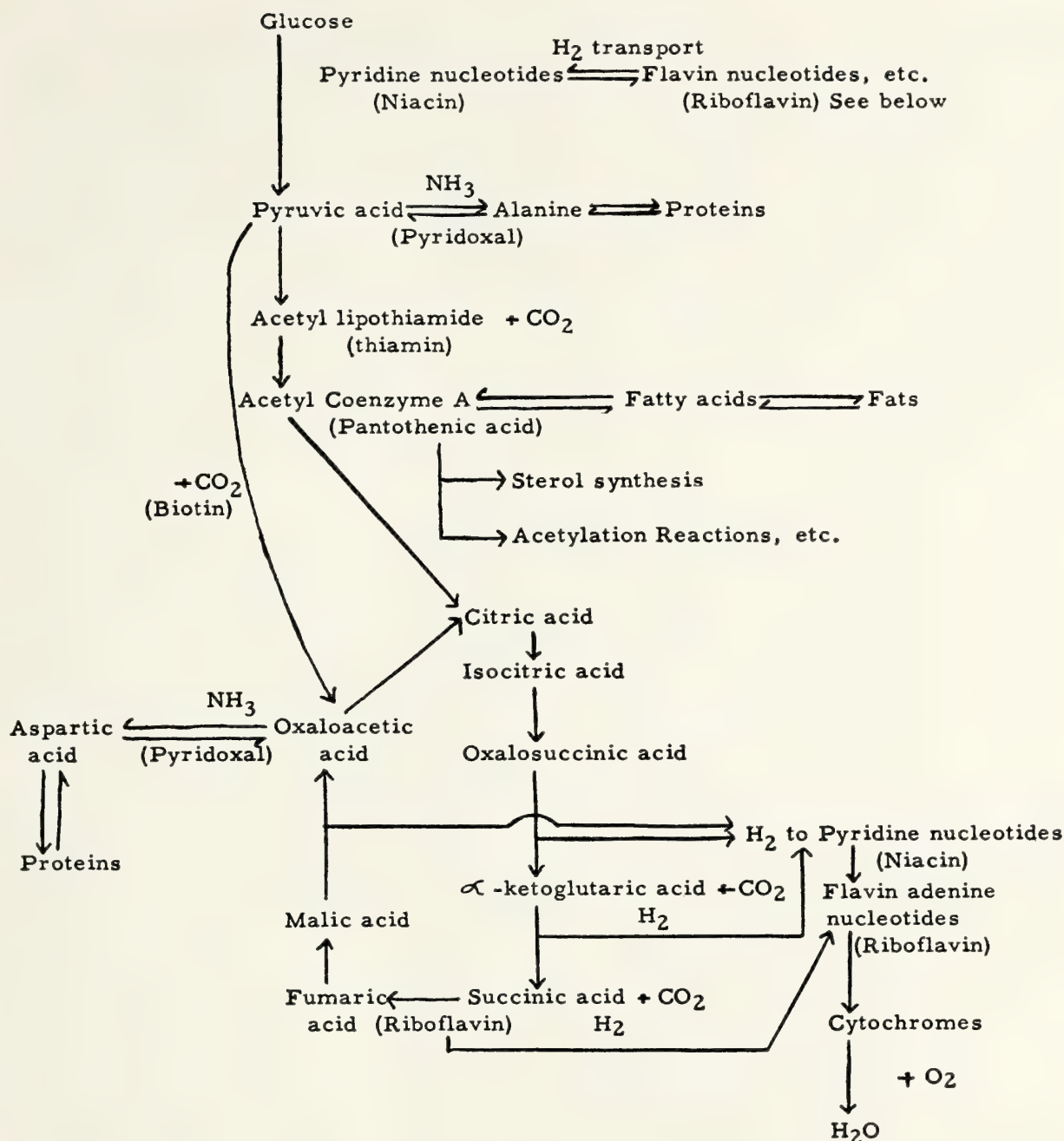


Figure 9-1. Schematic diagram showing some of the steps involved in the oxidation of glucose and the interrelations with fat and protein metabolism. The vitamins required to form the more complex coenzymes are indicated in parenthesis. The energy release at the various oxidative steps forms “high energy phosphate bonds,” usually adenosine triphosphate. This provides the energy in available form for synthetic purpose, muscular work, etc.

The enzymatic function of thiamine is reasonably well known. It is required for the decarboxylation of α -keto acids where the actually functioning compound is thiamine pyrophosphate, cocarboxylase, or the lipoic acid complex, lipothiamide³² (see Figure 9-1). As well be seen from Figure 9-1, glucose is oxidized to pyruvic acid by a number of steps not shown. This yields relatively little energy. The pyruvate then reacts with lipothiamide to yield the acetylated compound and carbon dioxide. The acetyl group is

passed on to coenzyme A and then reacts with oxaloacetic acid to form citric acid. Citric acid is oxidized by a number of rearrangements, decarboxylations and dehydrogenations to finally yield the original oxaloacetic acid. The energy of the pyruvate thus oxidized is utilized to form high energy pyrophosphate bonds such as adenosine-triphosphate at numerous steps in the scheme. The ATP thus formed is the "battery" which holds the energy in utilizable form for energy requiring reactions such as muscle work, synthesis of body constituents, heat production, etc. The relation of the development of the typical deficiency symptoms to a failure in the particular metabolic steps involving thiamin is not clear. In severe deficiency accumulations of pyruvic acid in the blood under standardized conditions may be noted.

The thiamine requirement seems to be largely determined by the amounts of carbohydrate and protein metabolized. Fat exerts a sparing effect presumably because its oxidation does not go through pyruvate. The minimum requirement is probably near 0.2 mg per 1000 nonfat calories although some workers have observed minor symptoms at considerably higher levels³³. Extra caloric rations during hard work, etc., do not appear to raise requirements in the proportion of 0.2 mg/1000 nonfat calories thus throwing some doubt upon the validity of this basis of calculation. Thiamine deficiency is easily produced by low thiamine rations in all species other than ruminants studied, but under special conditions intestinal synthesis sufficient to prevent the appearance of symptoms in human subjects has been observed.

Riboflavin. Riboflavin is the yellowish-green fluorescent pigment of whey. Milk and eggs are the best sources and the green leafy vegetables and meats are fair sources. Diets low in milk are generally low in riboflavin by modern standards. Although many diets in the world are undoubtedly low in riboflavin, the deficiency is seldom so severe as to cause death in contrast to thiamin and niacin, for example. This is probably due to either an adaptability of the organism to limited amounts or the distribution of the vitamin in small amount in many foods. The deficiency in man is shown principally by cheilosis (cracks at the corners of the mouth), a seborrheic dermatitis, glossitis and vascularizing keratitis. It is often associated with other dietary deficiencies. In experimental animals lack of growth and dermatitis in rats, paralysis in chicks, anemia and sudden collapse and death in dogs and monkeys have been observed.

Riboflavin occurs largely in the functional forms of riboflavin phosphate and the flavin adenine nucleotides. These are coenzymes for numerous enzymes such as succinic dehydrogenase, xanthine oxidase, cytochrome reductase, etc. The flavin moiety serves as a hydrogen transport system, receiving the hydrogen as the substrate is reduced and passing it on to another acceptor³⁴.

The minimum requirement for riboflavin in growing rats appears to be approximately 1.5 times the thiamin requirement. Studies upon human subjects indicate that 1.1 mg/day is minimum based upon urinary excretion data, higher levels result in increases in urinary output³⁵. In contrast to thiamin, data to date do not indicate a dependence upon caloric intake. High fat diets apparently increase requirements while certain carbohydrates such as dextrin may lower the need, presumably acting on a limited intestinal synthesis. The addition of riboflavin concentrates is a necessity in most modern poultry rations. Certain fermentation as well as chemical synthesis are available methods for its production.

Niacin. A deficiency of niacin produces pellagra in human beings. The production of its counterpart in dogs, black tongue, provided the means for the identification of the vitamin. The demonstration that nicotinic acid or niacin would cure or prevent pellagra failed to explain the antipellagra effect of milk which contains little niacin. This enigma has been at least partially explained by the finding that the amino acid tryptophan is converted to niacin within the body³⁶. Thus an evaluation of a diet requires consideration of both niacin and tryptophane. The efficiency with which tryptophan is converted to niacin has not been well quantitated and apparently varies with species. Niacin deficiency can only be produced in the rat on diets very low in tryptophan whereas it is easily produced in chicks and dogs upon diets containing usual amounts of protein. Man is probably intermediate. In addition there is increasing evidence that there are probably precursors or unavailable forms of niacin in certain foods³⁷. Thus the method of analysis, usually microbiologic, is suspect in terms of available niacin.

In human beings pellagra is characterized by glossitis, bilateral dermatitis on exposed areas, severe diarrhea and gastrointestinal symptoms and dementia. Dogs show principally the oral lesions. Other animals have shown primarily lack of growth. Deficiency symptoms have probably not been observed under practical conditions in species other than man and dogs. In these species it has usually been associated with the consumption of corn diets which contain proteins low in tryptophan. Riboflavin and other vitamin deficiencies such as folic acid often occur simultaneously.

Niacin functions as the di- and tri-phosphopyridine nucleotides. These serve as hydrogen acceptors and transporters for numerous enzymes in glycolysis and respiration (see Figure 9-1)³⁴.

Relatively little is known of its requirements. In human beings approximately 7 mg/day appears to be minimal in the presence of 200 mg of tryptophan in the diet³⁸. In dogs the requirement appears to be about 10 times the thiamin requirement. This is the basis of present estimates of the daily allowance for human beings also.

Pyridoxine (Vitamin B₆). Three forms of the vitamin occur naturally,

pyridoxine, pyridoxal and pyridoxamine. These are probably of nearly equal activity in animals although microbial species may require one or the other or be much more sensitive to one form. This provides the basis for differential determinations. The functional compound is pyridoxal phosphate, an essential coenzyme for the decarboxylation of certain amino acids and for the transamination of amino acids³⁴.

The natural occurring deficiency of vitamin B₆ has probably not been seen in any species other than recent reports of its development in infants fed certain prepared formulas³⁹. The deficiency has been induced in man by the administration of the antivitamin desoxypyridoxine where it was characterized by a dermatitis resembling that of pellagra⁴⁰. The most characteristic symptom in experimental animals is the development of a microcytic anemia. Convulsive seizures and loss of hair, red edematous paws, ears and lips are seen in rats.

The requirement is of the same order of magnitude as thiamin in rats and chicks. High levels of protein in the diet increase the requirement.

Pantothenic Acid. The coenzyme formed from pantothenic acid, coenzyme A, holds a central role in metabolism but deficiencies of this vitamin are rare or unrecognized, in man and animals under natural conditions. Experimentally the deficiency has been shown to produce a typical dermatitis in chicks, hemorrhagic adrenals in rats, intestinal bleeding and ulceration in several species, and grey hair or feathers in dark animals and birds⁴¹.

As may be seen from Figure 9-1, the metabolic schemes for carbohydrate, fat, and at least some amino acids converge in the formation of acetyl coenzyme A. The catabolism is thus dependent upon a sufficiency of CoA as are many anabolic schemes including the formation of fat, sterols, acetylation of various materials, and perhaps protein formation. The ubiquitous role of the coenzyme presumably explains the many different deficiency symptoms⁴¹.

The distribution of pantothenic acid is widespread in foods and this undoubtedly explains the failure of severe deficiency to occur. The so-called "burning foot syndrome" observed in prisoners of war in the Far East and elsewhere has been reported to respond to pantothenic acid⁴². Estimates of requirements in experimental animals indicate a need of about 10 to 15 mg/kg of feed, about 10 times the thiamin requirement.

Folic Acid and Folinic Acid. Although chicks were the first species to be shown to require folic acid, it is apparently of most importance under practical conditions in human nutrition. Several macrocytic anemias, those of sprue, pellagra, the macrocytic anemia of pregnancy and the tropics, respond to folic acid. It is likely that tropical sprue characterized not only by the anemia but also by fatty stools, gastrointestinal disease, and glos-

sitis, is largely the effect of folic acid deficiency⁴³. Avian species, monkeys, and some other species fail to grow in the absence of folic acid and develop anemia. The rat, however, has sufficient intestinal synthesis to make it independent of dietary supplies under most conditions.

Folic acid occurs combined with several different glutamic acid peptides. Also it is replaceable with folinic acid which is probably the active form of the vitamin. Folinic acid is more active in many conditions than folic acid. Although the metabolic action of folinic acid (folic acid) is not clear there is much evidence that it is concerned primarily with the metabolism of "one carbon fragments." The metabolism of formate, nucleic acid synthesis, and certain transmethylation reactions involve folic or folinic acid. Vitamin B₁₂ is involved in several of the same or related reactions⁴⁴.

The anemia of scurvy appears to be due to folinic acid deficiency because vitamin C is required for the transformation of folic acid into folinic acid. The anemia of pernicious anemia responds to folic acid but folic acid does not prevent the neurologic symptoms and should not be used⁴⁵.

Vitamin B₁₂. Vitamin B₁₂ is the antipernicious anemia factor long known to occur in liver. Since the occurrence of pernicious anemia is not related to a low intake of B₁₂, small doses are effective by injection, and large doses required orally, it is apparent that there is a defect in absorption in pernicious anemia. The so-called "intrinsic factor" formed by the stomach and duodenum and possibly a mucoprotein, is missing and required for efficient absorption⁴⁶.

This vitamin partially accounts for the essentiality of sources of animal protein in chick diets in the past since it is not present in most vegetable products. Growth responses in several species fed diets composed largely of vegetable products have been observed⁴⁷ and is of practical importance. Slight growth responses in children have been reported⁴⁸. Although vegetable materials generally are lacking in vitamin B₁₂, the commercial source is fermentation residues from aureomycin production. Various microorganisms thus produce it. Manure, sewerage, etc., are also sources. It appears that animal life is dependent upon microbial production.

Very small amounts are effective in both man and animals. Approximately 1 μ g/day is adequate treatment for pernicious anemia in human beings⁴⁶.

The structure is not completely known. The presence of cobalt is noteworthy (see Cobalt).

Choline. Choline has long been known to be a constituent of the phospholipids which occur in all tissues. A lack of choline produces fatty livers in most species, but in chicks the bone deformity, perosis, due to faulty metabolism of the cartilage cells is produced without the occurrence of liver disease. In the rat and probably most non-avian species, the dietary

need is for "labile methyl groups" which may be supplied by choline or methionine. If methionine is supplied adequately (both for methyl groups and to meet the requirement as an essential amino acid) choline is synthesized in adequate amount. The chick has limited ability in this direction and dietary choline is essential. In the rapidly growing rat the kidneys become hemorrhagic. If the degree of deficiency is such that the animals do not die, they recover, but a large proportion develop hypertension later due to the scarred kidney⁴⁹. Chronic fatty liver leads eventually to cirrhosis. Whether these findings are significant in the human diseases, hypertension and cirrhosis, is unknown. Once these are clearly established they are largely irreversible in the rat. Thus in human beings, adequate studies would probably have to be done prior to the development of the disease.

Feeding large amounts of materials which are methylated prior to excretion (nicotinamide, creatine, etc.) may induce choline deficiency⁵⁰. The requirements in most animals obviously depend upon the amount and kind of protein supplied (methionine). In the chick requirements are high compared to other vitamins and around 0.1 per cent of the ration.

Biotin. Biotin is synthesized by the gastrointestinal flora in many species probably including man. Domestic birds do require it in the diet. The deficiency may be produced in numerous, if not all, species by the feeding of large amount of raw egg white. This contains a protein, avidin, which combines with the biotin in the tract and renders it unavailable⁵¹. Denaturation by heating inactivates avidin. All species including man develop dermatitis. Deficiency has also been produced by feeding sulfa drugs which reduce the intestinal synthesis. No naturally occurring deficiency has been observed.

Although a coenzyme containing biotin has not been isolated, studies upon tissues of deficient bacteria and animals indicate that it must be involved in the fixation of CO₂⁵¹ (Figure 9-1).

Other Factors. Inositol is a constituent of many, if not all, tissues. Certain phospholipides contain inositol. It is required by some microorganisms and effects upon growth, reproduction, or liver pathology, have been reported under some conditions with several species⁵². It appears unlikely at this time that it is of practical importance.

Para-amino benzoic acid was first shown to reverse the bacteriostatic effect of sulfanilamide and later to be required by some bacteria⁵³. Various effects upon the growth and reproduction in animals have been reported but not well substantiated. It may be noted that it is a constituent of folic acid.

Wheat germ oil has been reported as the most potent source of an identified factor required for reproduction in rats⁵⁴.

There is evidence that babies may not grow normally when fed a purified diet that supports growth in young rats. Human breast milk is much

higher in an unidentified factor required by *L. bifidus* than is cow's milk. This may have importance in human nutrition⁵⁵.

Considerable study has been given to a condition in guinea pigs in which the joints become stiff and phosphorus metabolism is deranged⁵⁶. Certain sterols are apparently effective in the prevention of the disease which develops on high calcium diets.

Evidence of the occurrence in liver of a factor which is effective in resistance to stress of various kinds such as cold, high levels of thyroxine, and various toxic agents has been presented⁵⁷. Whole wheat has been identified as the best source of a factor which is active in promoting resistance to certain infections in mice⁵⁸.

MINERALS

Calcium and Phosphorus. Calcium and phosphorus are the minerals required in largest amounts. About 99 per cent of the calcium and 75 per cent of the phosphorus are present in the bones. Deficiencies are manifest chiefly by failure to deposit or loss of the bone salt. Since vitamin D, calcium, phosphorus and the parathyroid gland are all intimately related, the ultimate cause of rickets or osteomalacia is usually not known. Although it is often said that calcium lack is the most common deficiency in the dietary of man, pathological effects are extremely rare, and this author does not agree⁵⁹. It is likely that the vitamin D requirement may bear an inverse relationship to the calcium intake. Rickets and osteomalacia are essentially diseases of childhood and pregnancy and lactation when calcium requirements are obviously high. They respond primarily to vitamin D and not to calcium administration.

The metabolism and requirements are complicated by the many factors which influence absorption⁶⁰. High levels of calcium or phosphorus inhibit the absorption of the other. Much of the phosphorus in cereals exists as phytic acid (hexaphosphoric acid ester of inositol). This is utilized to a limited and variable extent and interferes with calcium absorption. Oxalates which occur in certain foods prevent calcium absorption. In most diets the net absorption of calcium is quite limited and of the order of 20 to 30 per cent. The source of phosphorus is of more practical importance. Pyrophosphates, metaphosphates, and certain rock phosphates are utilized to only a limited extent⁶¹.

The diets of man, poultry and pigs are generally low in calcium because of the high cereal intake. Calcium supplements for the latter two species are usually required⁶². On the other hand, forages are relatively low in phosphorus especially on soil of low phosphorus content. In these areas "aphosphorosis" is common in grazing animals⁶². The animals develop a depraved appetite, become unthrifty, lame and may suffer from broken bones.

Magnesium. Magnesium deficiencies, other than those produced ex-

perimentally, have been reported chiefly in cattle. Lactation tetany (grass staggers) has been reported as a magnesium deficiency but the evidence is not completely convincing. Malnutrition in milk fed calves has several characteristics similar to magnesium deficiency in experimental animals—tetany, deposition of calcium in the heart, aorta, etc.—yet milk is not especially low in magnesium. The explanation may be in the interrelationships between calcium and magnesium intakes⁶³. In rats the magnesium requirement for growth has been reported to be approximately 5 mg/100 grams of diet but because of the above interrelationship this value may mean very little. In growing children the requirement is thought to be about 13 mg per day per kg of body weight.

Other symptoms reported in deficient animals include a marked vasodilation and hyperemia which causes the tails, ears and feet of deficient rats to be a bright pink. Hyperirritability develops and finally severe tetanic seizures. Similar changes have been reported in dogs. Changes in bone composition occurs. Several papers report the development of kidney stones in animals fed low magnesium diets.

Numerous enzymes require magnesium as a coenzyme.

The various symptoms reported with magnesium deficiency and the interrelationships point to the need for further investigations.

Sodium and Chlorine. The essential nature of salt has been known for many years but the minimal requirements for sodium and chlorine are not very well established. They are ordinarily considered together. In man, salt and fluid loss together in the sweat from strenuous exercise, usually at high temperatures, leads to cramps and prostration. Gradual salt depletion leads to weakness, fatigue, anorexia, nausea and thirst not alleviated by water. At high temperatures a man may lose 10 to 15 liters of sweat per day, each liter containing about 3 grams of salt. However, the body shows considerable adaptive ability and if the individual is gradually acclimatized the salt losses in sweat may be small although the fluid losses remain large and both must be replaced⁶⁴. Under ordinary conditions, man's daily intake of approximately 10 grams of salt is many times his apparent requirement. During recent years low sodium diets supplying approximately 200 mg of sodium or less and a like amount of chlorine, have been widely used in the treatment of hypertension⁶⁵. Unless kidney function is abnormal, deficiency does not occur.

The relatively low sodium content of vegetable materials makes it much more important to supplement the diets of herbivores. High producing cows in particular require salt to replace losses in the milk. Since salt is ordinarily supplied *ad libitum* few nutritional standards have been developed.

Potassium. Whereas sodium and chloride are the chief extracellular cations in the body, most of the potassium occurs within the cells. Dietary

deficiencies are practically unknown because of the high level in most foods. In recent years the occurrence of potassium deficiency in patients fed largely by intravenous methods (usually saline and glucose) has been recognized⁶⁶. Rapid gains in tissue during rehabilitation of the ill imply large potassium requirements as well as other nutrients. Potassium will be limiting, however, only under very unusual circumstances.

Manganese. Manganese is of practical importance in poultry feeding where a deficiency produces the bone deformity called "perosis." The lesion is in the developmental cartilage of the bones. Eggs laid by hens fed diets low in manganese have a poor hatchability and the embryos have shortened leg and wing bones and distorted beaks⁶⁷. Manganese activates the enzyme phosphatase *in vitro* and the phosphatase level of the blood is reduced in perotic chicks. Numerous other enzymes are activated by manganese. High levels of calcium and phosphorus increase the manganese requirement.

Manganese deficiency has also been produced experimentally in mice, rats, and rabbits⁶⁸. Since deficiency in other farm animals has not been observed, their requirements are likely considerably lower than poultry.

Cobalt. Cobalt deficiency resulting primarily in a severe anemia occurs in cattle and sheep in many areas of the world where the soil and thus the forage is low in cobalt. Herbage containing 0.1 ppm of the dry matter apparently just protects from deficiency. The deficiency is not observed in horses grazed upon the same areas and attempts to produce the deficiency in laboratory animals have been unsuccessful⁶⁹. Since the only known function of cobalt to date is as a constituent of vitamin B₁₂, it would appear that the ruminants are relatively less efficient in the synthesis of B₁₂ than certain other species or that their requirements are high. The problem of cobalt requirements in various species has not been well studied since its role as a component of vitamin B₁₂ has become known but cobalt will not replace vitamin B₁₂ in several species (see vitamin B₁₂).

Iron and Copper. The need for iron is believed to be directly related to rate of growth or blood loss. The body has practically no ability to excrete iron in the urine or stools, hence control over absorption is essential. This is exercised by the intestinal wall and iron absorption is related to iron need and the level of available iron in the diet. Normal adult man has practically no iron requirement. In adult women the iron need is related to menstrual blood losses or fetus formation. Iron deficiency anemia is not uncommon in women and children but in adult men it is only found in relation to blood losses, intestinal parasites, intestinal bleeding, etc.

The availability of iron in foods is variable and the absorption of iron may be insufficient to meet the needs after severe anemia is established. High levels of iron dosage may be the only effective method of treatment.

Approximately 5 grams of iron occur in the normal man, most of which

is present in the red blood cells. These are destroyed at a rate which liberates approximately 25 mg of iron daily, and normally this will be reutilized for new red cell formation.

The deficiency symptoms are the pallor, fatigue, etc., associated with the microcytic hypochromic anemia as well as glossitis, angular stomatitis and dysphagia in the severe cases. In animals the deficiency is a practical problem when young pigs are raised in pens without access to the ground. Milk is extremely low in iron but most animals are born with sufficient iron reserves to carry them through the nursing period. The iron requirements of most species has received relatively little attention.

Copper deficiency produces an anemia due to an inability of the body to utilize iron. The deficiency is not observed in man but it not uncommon in cattle and sheep consuming forages low in copper⁶⁹. High molybdenum intakes induce copper deficiency for unknown reasons. The disease is characterized by wasting, staggering, falling and instantaneous death. It has been identified by many names such as "swayback and falling disease." A copper content of 7.5 ppm in herbage is believed to be adequate and a daily intake of 5 mg of copper for pregnant ewes has been suggested. High levels of copper are, of course, toxic.

Iodine. Iodine deficiency in man and animals is widespread in many parts of the world. The most common symptom is thyroid enlargement, goiter, although the ultimate cause and the sequela are not clear. More severe or longstanding deficiency leads to cretinism. Breeding difficulties in all domestic animals, hairlessness in new born pigs, and high mortality associated with goiter in sheep, swine, colts and calves are found in the low iodine areas. Many areas including the central part of the United States, the Alps and surrounding areas, the Andes of South America, are severely lacking in iodine. It has been shown conclusively that iodine administration will essentially eradicate the disease in both man and animals. This is most effectively done by the distribution of iodized salt. In spite of this evidence and the fact that recommendations for such action have been made repeatedly for over 100 years, the incidence of endemic goiter is still enormous and sometimes approaches 100 per cent incidence in many parts of the world. A sad commentary upon the utilization of cheap and effective public health methods.

Although iodine administration is effective, there is considerable evidence that iodine requirements are variable. Goitrogenic factors have been demonstrated in some plant materials, particularly the *Brassica*. There is some evidence that the intake of other minerals may be related to iodine requirements and age and sex are undoubtedly important.

The only known function of iodine in the body is for the formation of the thyroid hormone. The hormone is necessary for proper growth and de-

velopment and the regulation of energy metabolism but the biochemistry of its operation still eludes us.

Under usual conditions the requirement of iodine in man is approximately 1 to 2 $\mu\text{g}/\text{kg}$ of body weight per day.

Fluorine. Interest in fluorine centers upon its effects upon tooth decay. No adequate evidence is available to indicate any other detrimental effect when low fluorine diets are fed. It has been established under experimental conditions and where natural waters contain fluorine that approximately 1 ppm fluorine is a desirable level⁷⁰. Fluorine exerts its principal effect during the development of the teeth. A 50 per cent reduction in the incidence of dental caries in children has been observed in several areas after fluoridation of the water supply was begun⁷¹. The effect is identical to that which was expected from studies upon populations consuming natural water supplies which contained this level of fluorine.

Like all other nutrients, fluorine is toxic when consumed in excess. At levels somewhat above 1 ppm mottled enamel is observed and at very high levels bone deformities may be produced. There is no evidence, however, that any untoward effect will be produced at 1 ppm. It is unfortunate that studies upon fluorine were first concerned with the toxicity produced in cattle fed high fluorine phosphate mineral supplements. The association with toxic effects has greatly hampered the fluoridation of water supplies and, like all public health measures, it has had very vociferous and active opposition.

The problems of tooth decay which impose a medical burden of some 1.5 billion dollars per year upon the United States population have received relatively little study. However, with the production of caries in experimental animals several important factors have been delineated. Animals may be bred for susceptibility or resistance to tooth decay so there is a genetic factor. Animals raised under sterile conditions with no oral flora do not develop decay thus showing the importance of the oral microorganisms. Animals fed by stomach tube so that there is no material to support the oral flora do not develop caries. Certain dietary constituents still unidentified, are of importance during the development of the teeth in producing caries resistance. The amount of fermentable carbohydrate and size of food particles have also been implicated. Other nutrients popularly associated with the development of sound teeth such as vitamin D, calcium, etc., are of undoubted importance in tooth development but their relation to dental caries under practical conditions has not been well established.

Other Minerals. In recent years molybdenum has been identified as an essential nutrient for rats. Low levels of xanthine oxidase are found in animals fed molybdenum diets and the mineral has been identified as an essential part of the enzyme. Other deficiency signs have not been reported⁷².

Zinc is similarly essential for rats and presumably other animals. It is required for the function of the enzyme, carbonic anhydrase⁷³. Naturally occurring deficiencies have not been found. Zinc toxicity from the use of zinc containing containers for the acid foods has been occasionally observed⁷⁴.

Boron has not been shown to be required by animals although it is essential for plants. Feeding diets very low in aluminum, vanadium, silicon, strontium, barium, and other minerals have failed to demonstrate a need in rats nor are they known to be required by other species. Since cobalt deficiency can only be demonstrated in certain species by these methods, the possibility that they play a role cannot be completely eliminated.

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10. STORAGE OF AGRICULTURAL RAW PRODUCTS^{*}

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Because the production of agricultural commodities is seasonal they must usually be stored until consumed or processed. The storage of agricultural raw products will be discussed in this chapter, giving recommended practices for storage, the causes of deterioration and loss, and approximate storage life. The food crops covered are fruits and vegetables, eggs, milk, fresh meat, poultry and fish, grains, and seeds.

Storage Factors

What makes a commodity perishable and hard to store? What are the problems of storage? Before we get much farther in this discussion it will be apparent that each commodity is likely to present peculiar problems, but there are some general conclusions to be made as follows:

(1) Microbiological activity must be arrested. Growth of fungi or bacteria in storage is a major problem with most commodities. Bacterial spoilage is the limiting storage factor for meat, fish, poultry, milk and eggs. Bacteria and fungi cause heavy losses in fruits and vegetables, grains and seeds. Fungi also damage eggs and meat in storage.

(2) Respiration must be retarded in plant products. Fruits, vegetables, nuts, grains, and other seeds are all alive and respiring. Seeds and nuts are rather inactive until they take up enough moisture to start germination; then they live at a fast pace if held at a warm enough temperature. Respiration rates in terms of heat evolved are given in Table 10-1 for a number of

^{*} We wish to acknowledge the "Refrigerating Data Book," published by the American Society of Refrigerating Engineers, as a source of information in the preparation of this chapter.

TABLE 10-1.* HEAT^a EVOLVED IN THE RESPIRATION OF FRUITS AND VEGETABLES

Commodity	Btu per ton per 24 hr		
	32°F	40°F	60°F
Apples-Jonathan Wine-sap	300 to 800	590 to 840	2,270 to 3,470
Beans, green	5,500 to 6,160	9,160 to 11,390	32,090 to 44,130
Broccoli	7,450	11,000 to 17,600	33,870 to 50,000
Cabbage	1,200	1,670	4,080
Carrots, topped	2,130	3,470	8,080
Celery	1,620	2,420	8,220
Corn, sweet	6,560	9,390	38,410
Onions	660 to 1,100	1,760 to 1,980 ^b	—
Oranges	420 to 1,030	1,300 to 1,560	3,650 to 5,170
Peaches	850 to 1,370	1,440 to 2,030	7,260 to 9,310
Pears—Bartlett	660 to 880	—	8,800 to 13,200
Peas, green	8,160	13,220	39,250
Potatoes	440 to 880	1,100 to 1,760	2,200 to 3,520
Spinach	4,240 to 4,860	7,850 to 11,210	36,920 to 38,000
Strawberries	2,730 to 3,800	3,660 to 6,750	15,640 to 20,280
Sweet potatoes	1,190 to 2,440	1,710 to 3,350	4,280 to 6,300
Tomatoes, mature green	580	1,070	6,230
ripe	1,020	1,260	5,640

^a Heat values obtained by multiplying respiration rate in mg of CO₂ per kilo per hour by 220.

^b At 50°F.

* Adapted from "U. S. Dept. of Agr. Handbook 66," table 1¹.

fruits and vegetables held at different temperatures. Animal products such as meat, poultry, and fish do not respire. In the case of eggs respiration is a moot question, and is not of importance as a storage factor.

(3) In plant and animal tissues chemical processes go on that call for control. Some processes such as aging of beef and ripening of fruits are desirable if not carried too far. High temperatures usually accelerate these changes just as it does respiration. With some fruits and vegetables, certain cold temperatures are to be avoided, for they favor abnormal changes evidenced by chilling injury.

(4) Loss or gain of moisture may be harmful. Here we have the problem of keeping some commodities like grains, seeds, and nuts from gaining moisture lest they support growth of microorganisms and become physiologically active and, on the other hand, of maintaining high enough humidities to keep most fruits and vegetables, meats, and eggs from drying out in storage.

(5) Insect damage must be prevented. The activity of insects is the greatest single cause of damage to grains and seeds in storage. Insects are not a major factor in the storage of the other commodities.

Temperature has a fundamental influence on each of the factors that cause spoilage. The activity of microorganisms is markedly affected by temperature and so are the respiration processes and chemical changes within the cells of the commodity. In general, for each rise of 18°F within a range of say 32 to 80°, microbiological activity, respiration and other chemical reactions increase two to three times. Some bacteria and molds cannot grow at cold storage temperatures, thus quick cooling to low temperatures is a means of avoiding trouble from these microorganisms. The activity of stored-product insects is practically nil at temperatures of 45° or lower. And at low temperatures gain or loss of moisture goes on much more slowly than at higher temperatures.

Humidity is often a serious storage problem in cold storage and too low humidities are more frequently encountered than too high ones. What can be done when the storage room air is too dry and the fruit or vegetable shows wilting or meat shows surface drying? Protective packaging with moisture vapor resistant film may be an easy solution. Increasing the humidity of the storage room air is often difficult, for moisture may be removed on the coils or brine spray of the refrigeration system as fast as it is added. A corrective measure is to provide enough coils or brine sprays to permit them to be held only a few degrees lower than the room temperature. Then the air will be cooled only a few degrees, and will not have much water vapor condensed from it as it passes over the coils or sprays. When low humidities are wanted, drying the air by passing it over low-temperature coils and reheating it if necessary, or using desiccants such as silica gel or calcium chloride can be resorted to.

The condensation of moisture on commodities removed from cold storage may give concern. To prevent this requires removal to air with a dewpoint lower than the temperature of the commodity. For example, if the commodity is 32°F when removed from storage, the humidity of 95° air must be less than 10 per cent to avoid condensation (Table 10-2). If the air is 75°, its humidity must be less than 20 per cent. The warmer the commodity, the higher the dewpoint and humidity of the air that can be tolerated. Packaging may alleviate the problem by making the condensate form on the surface of the package instead of on the commodity. Warming the commodity and accelerating drying by air circulation are also helpful.

Fruits and Vegetables

Fruits and vegetables offer more storage problems than other foodstuffs because they are physiologically active, they can be easily invaded by spoilage organisms, they will freeze if subjected to temperatures much below 32°F and they are generally susceptible to moisture loss. A good temperature for one fruit or vegetable may be very harmful for another, and the same is true for humidity. Recommended storage temperatures, humidities,

TABLE 10-2. DEWPOINTS OF AIR IN RELATION TO TEMPERATURE AND HUMIDITY

Dewpoint (°F)	Relative humidity at indicated temperatures						
	95°	85°	75°	65°	55°	45°	35°
	Pct	Pct	Pct	Pct	Pct	Pct	Pct
32	10	15	20	28	40	60	87
40	15	20	28	40	57	82	
45	18	24	33	47	68	100	
50	21	29	40	57	82		
55	25	35	48	68	100		
60	30	42	58	83			
65	35	50	70	100			
70	43	60	83				

approximate storage life, and average freezing points for fruits and nuts are given in Table 10-3, which is adapted from Wright, Rose and Whiteman¹. Similar information for vegetables is given in Table 10-4.

Lowering the temperature of fruits and vegetables slows down their metabolic activities and thereby checks the processes of deterioration. It does the same thing to bacteria and fungi that cause decay. Since the retarding effect is in proportion to temperature reduction, it should follow that the lower the storage temperature short of freezing the commodity, the longer the storage life. This does not hold for a considerable number of fruits and vegetables as indicated in Tables 10-3 and 10-4. They cannot be given the limit of refrigeration because at the cold temperatures they develop abnormalities which may spoil their flavor and appearance and make them more susceptible to decay. This damage is known as chilling injury and it is believed to be due to an upset in the cell functions caused by low temperatures. Many fruits and vegetables are unknowingly stored at too low temperatures. The fruits and vegetables susceptible to cool temperatures are listed in Table 10-5. Varieties of fruits and vegetables differ in their susceptibility to chilling injury. Very often the least mature specimens are more easily injured than the mature ones. Usually the further the temperature is below the critical point, the more quickly the fruit or vegetable is injured. The symptoms of chilling injury may not appear in storage but develop more seriously when the commodity is held for several days at a warm temperature. If the fruit or vegetable can be processed or used very soon after removal from storage, chilling damage can often be avoided. This may be of interest to the processor who would like to use a low temperature to control decay in a commodity subject to chilling injury. He can get away with it if he does not overdo it, holding the fruit or vegetable so long that its quality is damaged in storage. Varietal differences and storage behavior

TABLE 10-3.* RECOMMENDED STORAGE TEMPERATURES, RELATIVE HUMIDITIES, APPROXIMATE STORAGE LIFE AND AVERAGE FREEZING POINTS OF FRUITS AND NUTS

Commodity	Storage temperature (°F)	Relative humidity (%)	Approximate storage life	Average freezing point (°F)
Apples.....	30 to 31 ^a	85 to 90	^a	28.4
Apricots.....	31 to 32	85 to 90	1 to 2 weeks	28.1
Avocados.....	37 to 48 ^a	85 to 90	^a	27.2
Bananas.....	53 to 60 ^a	85 to 90	1 to 3 weeks	^b
Berries				
Blackberries.....	31 to 32	85 to 90	7 to 10 days	28.9
Dewberries.....	31 to 32	85 to 90	7 to 10 days	29.2
Gooseberries.....	31 to 32	85 to 90	3 to 4 weeks	28.9
Loganberries.....	31 to 32	85 to 90	7 to 10 days	29.5
Raspberries				
Black.....	31 to 32	85 to 90	7 to 10 days	29.9
Red.....	31 to 32	85 to 90	7 to 10 days	30.4
Strawberries.....	31 to 32	85 to 90	7 to 10 days	29.9
Cherries.....	31 to 32	85 to 90	10 to 14 days	^c
Coconuts.....	32 to 35	80 to 85	1 to 2 weeks	25.5
Cranberries.....	36 to 40	85 to 90	1 to 3 months	27.3
Figs.....	31 to 32	85 to 90	10 days	—
Grapefruit.....	See text	85 to 90	^a	28.4
Grapes				
Vinifera.....	30 to 31	88 to 92	3 to 6 months	24.9
American.....	31 to 32	80 to 85	3 to 8 weeks	27.5
Lemons.....	55 to 58	85 to 90	1 to 4 months	28.1
Limes.....	45 to 48	85 to 90	6 to 8 weeks	29.3
Mangos.....	50	85 to 90	15 to 20 days	29.8
Nuts.....	32 to 36	65 to 70	8 to 12 months	^d
Olives.....	45 to 50	85 to 90	4 to 6 weeks	28.5
Oranges.....	See text	85 to 90	8 to 10 weeks	^e
Papayas.....	45	85 to 90	15 to 20 days	30.1
Peaches.....	31 to 32	85 to 90	2 to 4 weeks	29.4
Pears.....	29 to 31	88 to 92	2 to 7 months	^f
Persimmons.....	30	85 to 90	2 months	28.3
Pineapples				
Mature green.....	50 to 60	85 to 90	3 to 4 weeks	29.1
Ripe.....	40 to 45	85 to 90	2 to 4 weeks	29.9
Plums, prunes.....	31 to 32	85 to 90	3 to 8 weeks	28.0
Pomegranates.....	31 to 32	85 to 90	2 to 4 months	28.0
Quinces.....	31 to 32	85 to 90	2 to 3 months	28.1

^a See text for varietal differences.

^b Green bananas 30.2°F, ripe bananas 26.0°.

^c Sweet cherries 24.5°F, sour cherries 28.0°.

^d English walnuts 20.0°F, pecans 19.6°, chestnuts 23.8°, filberts 14.1°, peanuts, shelled 13.2°.

^e Peel 27.4°F, flesh 28.0°.

^f Anjou 26.9°F, Bartlett 28.5°.

* Adapted from "U. S. Dept. of Agr. Handbook 66," table 3¹.

TABLE 10-4.* RECOMMENDED STORAGE TEMPERATURES, RELATIVE HUMIDITIES, APPROXIMATE STORAGE LIFE AND AVERAGE FREEZING POINTS OF VEGETABLES

Commodity	Storage temperature (°F)	Relative humidity (%)	Approximate storage life	Average freezing point (°F)
Artichokes, Jerusalem	32	90 to 95	2 to 5 months	27.5
Asparagus	32	90 to 95	3 to 4 weeks	29.8
Beans				
Green	45	85 to 90	8 to 10 days	29.7
Lima—unshelled	32	90 to 95	2 to 4 weeks	30.1
shelled	32	90 to 95	15 days	30.1
Beets				
Topped	32	90 to 95	1 to 3 months	26.9
Not topped	32	90 to 95	10 to 14 days	26.9
Broccoli, Italian	32	90 to 95	7 to 10 days	29.2
Brussels sprouts	32	90 to 95	3 to 4 weeks	—
Cabbage	32	90 to 95	3 to 4 months	31.2
Carrots				
Topped	32	90 to 95	4 to 5 months	29.6
Not topped	32	90 to 95	10 to 14 days	29.6
Cauliflower	32	90 to 95	2 to 3 weeks	30.1
Celery	31 to 32	90 to 95	2 to 4 months	29.7
Corn, green	31 to 32	90 to 95	4 to 8 days	28.9
Cucumbers	45 to 50	90 to 95	10 to 14 days	30.5
Eggplants	45 to 50	90 to 95	10 days	30.4
Endive	32	90 to 95	2 to 3 weeks	30.9
Garlic	32	70 to 75	6 to 8 months	25.4
Horseradish	32	90 to 95	10 to 12 months	26.4
Leeks, green	32	85 to 90	1 to 3 months	29.2
Lettuce	32	90 to 95	2 to 3 weeks	31.2
Melons (ripe)				
Watermelon	36 to 40	80 to 85	1 to 2 weeks	a
Muskmelon	40 to 50	80 to 85	10 to 14 days	b
Honeydew	40 to 50	80 to 85	2 to 4 weeks	c
Casaba, Persian	40 to 50	80 to 85	4 to 6 weeks	—
Mushrooms	32	85 to 90	5 days	30.2
Okra	50	85 to 95	2 weeks	30.1
Olives	45 to 50	85 to 90	4 to 6 weeks	28.5
Onions	32	70 to 75	6 to 8 months	30.1
Parsnips	32	90 to 95	2 to 4 months	28.9
Peas, green	32	85 to 90	1 to 2 weeks	30.0
Peppers, green	45	85 to 90	8 to 10 days	30.1
Potatoes	38 to 40 ^d	85 to 90	6 to 9 months	28.9
Pumpkins	50 to 55	70 to 75	2 to 6 months	30.1
Rhubarb	32	90 to 95	2 to 3 weeks	28.4
Rutabagas	32	90 to 95	2 to 4 months	29.5
Spinach	32	90 to 95	10 to 14 days	30.3
Squashes				
Summer	40 to 50	85 to 95	2 to 3 weeks	—
Winter	50 to 55	70 to 75	4 to 6 months	29.3

Commodity	Storage temperature (°F)	Relative humidity (%)	Approximate storage life	Average freezing point (°F)
Sweet potatoes	55 to 60	80 to 85	4 to 6 months	28.5
Tomatoes				
Ripe	40 to 50	85 to 90	7 to 10 days	30.4
Mature green	55 to 70 ^d	80 to 85	3 to 5 weeks	30.4
Turnips—topped	32	90 to 95	4 to 5 months	30.5

^a Rind 28.8°F, flesh 29.2°.

^b Rind 28.4°F, flesh 29.0°.

^c Rind 28.8°F, flesh 29.0°.

^d See text.

* Adapted from "U. S. Dept. of Agr. Handbook 66," table 8¹.

of the important fruits and vegetables are discussed in the following sections.

Apples. Some varieties of apples can be stored until early summer if they are cooled quickly and held at the correct temperature and humidity. The storage life of different varieties of apples is shown in Table 10-6. As a general recommendation, the best storage temperature for apples is 30 to 31° F with a humidity of 88 to 90 per cent. Comparative tests have shown that 30° will give about 25 per cent longer storage life than 32°. Delays in cooling the fruit shorten its storage life. One day at 70° is equivalent to about 10 days at 32° in its effect on ripening.

Apple Scald. In the storage of apples it is important to know what storage disorders to expect and the methods of avoiding them. Apple scald, a disease of physiological origin, is probably the most important storage disease of apples. As indicated in Table 10-6 some varieties like Grimes Golden, Stayman, York Imperial, Rhode Island Greening and Arkansas have a tendency to scald severely. Affected fruits develop superficial browning of the skin, usually not until they are removed from storage and warmed. Scald is most apparent on the unblushed side of the apple. The disease is believed to be caused by a volatile or its precursor produced by the apple itself. It can be controlled fairly well by wrapping the apples in oiled wraps or scattering through the package shredded oiled paper (1½ lb per bushel). Oiled paper is made commercially by paper companies supplying the fruit industry. Immature fruit is more susceptible to scald than mature fruit and it develops more rapidly at high storage temperatures (36 to 40°F) than at 30 to 31°. To get the most benefit from oiled paper the apples should be in contact with it soon after harvest.

Brown Core, Internal Browning and Control by Gas Storage at 36 to 40°F. Other storage problems that deserve special consideration are brown core of northeastern McIntosh and internal browning of Yellow Newtown grown under cool weather. Sometimes Rhode Island Greening, Twenty Ounce

TABLE 10-5.* FRUITS AND VEGETABLES SUBJECT TO INJURY FROM EXPOSURE TO COOL, NONFREEZING TEMPERATURES

Commodity	Harmful temperatures (°F)	Limit of safe exposure	Kind of injury
Apples, certain varieties.....	Below 34 to 36	See text	Internal browning, soggy breakdown, soft scald
Avocados, most varieties.....	Below 45	1 to 2 months, differing with variety	Browning of flesh and skin
Bananas, some varieties.....	Below 55	Few hours to several days	Dull or brown skin color when ripened
Beans, green.....	Below 45	3 to 5 days	Pitting, russeting
Cranberries.....	Below 34	4 weeks	Flesh breakdown
Cucumbers.....	Below 50	2 days	Pitting, watersoaked spots, decay
Eggplant.....	Below 50	4 days	Pitting, bronzing
Grapefruit.....	Below 50	4 to 6 weeks	Pitting, scald, watery breakdown, internal browning
Lemons.....	Below 50 to 55	4 weeks	Pitting, browning, membranous stain
Mangoes.....	Below 50	2 to 3 weeks	Flesh browning
Melons			
Cantaloups.....	Below 45 to 50	4 to 8 days	Pitting, surface decay, off flavors
Honeydew.....	Below 45 to 50	4 to 8 days	Pitting, surface decay, off flavors
Casaba.....	Below 45 to 50	4 to 8 days	Pitting, surface decay, off flavors
Persian.....	Below 45 to 50	4 to 8 days	Pitting, surface decay, off flavors
Watermelons.....	Below 36	4 to 8 days	Pitting, surface decay flavors
Okra.....	Below 45	5 to 7 days	Watersoaked areas, discoloration
Olives.....	Below 45	4 to 6 weeks	Flesh browning
Oranges, Calif.....	Below 35 to 37	5 to 8 weeks	Rind pitting
Papayas.....	Below 45	1 to 3 weeks	Flesh breakdown
Peppers, green.....	Below 45	10 to 15 days	Pitting, browning
Pineapples.....	Below 45	1 to 3 weeks	Dull green color when ripened
Potatoes, some varieties.....	Below 40	2 to 4 weeks	Flesh browning
Squash			
Summer.....	Below 45	4 to 8 days	Pitting, decay
Winter.....	Below 50 to 55	4 weeks	Decay

Commodity	Harmful temperatures (°F)	Limit of safe exposure	Kind of injury
Sweet potatoes	Below 55	1 to 3 weeks	Decay, pitting, internal discoloration
Tomatoes, mature . .	Below 55	7 to 10 days at 50	Poor color when ripe, decay
green		6 to 8 days at 40	

* Adapted from "U. S. Dept of Agr. Handbook 66," table 3¹.

TABLE 10-6.* STORAGE LIFE AND STORAGE DISORDERS OF DIFFERENT VARIETIES OF APPLES

Variety	Maximum storage life, months	Tendency to scald	Other storage disorders
Gravenstein	3	Slight	Bitter pit, Jonathan spot
Wealthy	3	Slight	Soft scald, Jonathan spot
Grimes Golden	4	Severe	Soggy breakdown, bitter pit, shrivel
Jonathan	4	Slight	Jonathan spot, soft scald, breakdown
McIntosh	4 to 5	Slight	Brown core, soft scald
Cortland	5	Medium	Breakdown
Rhode Island Greening..	6	Severe	Bitter pit, breakdown
Golden Delicious	6	Very slight	Shrivel, soggy breakdown
Delicious	6	Slight to medium	Bitter pit, water core, breakdown, soft scald
Stayman	5 to 6	Severe	Breakdown, water core
York Imperial	5 to 6	Severe	Bitter pit
Arkansas	6	Severe	Bitter pit, water core
Northern Spy	6	Slight	Bitter pit
Baldwin	6 to 7	Medium to severe	Bitter pit
Rome Beauty	6 to 7	Medium to severe	Bitter pit, soft scald, breakdown, Jonathan spot
Ben Davis	8	Medium	—
Winesap	8	Medium	Water core
Yellow Newton	8	Slight	Bitter pit, internal browning (California)

* Adapted from "U. S. Dept. of Agr. Handbook 66," table 4¹.

and Baldwin from New York and the New England States also show this trouble². Brown core and internal browning, characterized by browning of the flesh of the apple usually in the core area, are probably identical. They develop in apples stored at temperatures below 36 to 40°F. The corrective measure is to modify storage temperature for susceptible apples. California Yellow Newtowns are stored at 36 to 37° to help prevent internal browning; 40° would be better but the fruit ripens too fast at this temperature.

Gas storage, that is, holding the fruit in atmospheres enriched in carbon

dioxide and depleted in oxygen as compared with normal air, is used widely in England and northern Europe and to some extent in this country to prolong the life of apples that must be held at 36 to 40°F. For McIntosh and most of the other varieties tested in New York, 5 per cent carbon dioxide and 2.5 to 3 per cent oxygen were best. Varieties differ in their tolerance to gas storage. The practical difficulties in gas storage are the cost of making a room gas tight, the inconvenience of having to seal a room and not enter it for the storage season, and the constant attention that must be given to maintaining the desired concentrations of carbon dioxide and oxygen. The fruit builds up the carbon dioxide concentration in the room through respiration and lowers the oxygen level by using oxygen in respiration. The volume of oxygen used is about equal to that of the carbon dioxide given off. If the desired concentrations are 10 per cent carbon dioxide and 11 per cent oxygen, as is the case for California Yellow Newtowns, the room would have to be ventilated with fresh air to maintain these concentrations after they were reached. If the sum of carbon dioxide and oxygen concentrations desired is less than that of normal air, or 21 per cent, the carbon dioxide level would be lowered to the desired concentration by scrubbing the air through an alkaline solution such as sodium hydroxide. After the desired oxygen level was reached by depletion through respiration, ventilation with fresh air would be employed to hold the oxygen level constant. The slowing down of metabolic processes accomplished by gas storage extends beyond the storage period itself into the post-storage life, giving the fruit an extended market life. The process must be worked out for each kind and variety of fruit or vegetable since serious injury can occur from too little oxygen or too much carbon dioxide. Injury is manifested by foul flavors and odors and death and browning of the tissue.

Other Physiological Troubles. *Bitter pit* of apples shows as sunken spots on the surface of the apple, usually just under the skin and consisting of brown spongy tissue, usually are not bitter in taste as the name indicates. It is believed to be related to sudden changes in the water relation of the tree. The disease is most severe on immature fruit of some varieties such as Gravenstein, Grimes Golden, Northwest Greening, Delicious and York Imperial. It can become more severe in storage. *Jonathan spot* is characterized by black or brownish spots of irregular shape on the skin of the apple, usually on the red side. It is favored by overmaturity, too high storage temperature and too long storage. Jonathan, Wealthy, Gravenstein, and Rome Beauty are susceptible varieties. *Soft scald* manifests itself as sunken sharply margined brown areas on the apple. The affected tissue may be as deep as $\frac{1}{4}$ or $\frac{1}{2}$ inch and is easily distinguished from apple scald, which is primarily a superficial skin disease. Soft scald may be properly considered in the same category as chilling injury, for it occurs on fruit held at 30 or

31°F and not at 36°. One method of control is to store the fruit at 36°, but this shortens storage life. Another method is to store the fruit at 34° for 8 weeks and then lower the temperature to 0 to 31°¹. Jonathan, Wealthy, Delicious and Rome Beauty are susceptible. *Soggy breakdown* is a soft, watery breakdown of the flesh similar to that of soft scald, but it may not be visible on the surface of the apple. It is caused by too low storage temperature, and storage at 36 to 38° is generally employed to control it on susceptible fruit such as Grimes Golden. Internal breakdown is manifested by a brown dry mealy disintegration of the flesh, a sign of the end of storage life. Large apples usually show the trouble first and overmaturity at harvest, delay in cooling, and too high storage temperatures favor the disease. Jonathan, Stayman, and Rome Beauty are susceptible varieties. *Shrivel* is a serious storage trouble of Golden Delicious and Grimes Golden apples, for they do not have skins as resisant to water loss as other storage varieties. Lining the storage containers with plastic film such as polyethylene and pliofilm and leaving them unsealed have helped to protect the fruit. The humidity of the storage room air should be maintained near 90 per cent. *Water core*, a disease that gives the flesh a translucent appearance, often affects late-picked Delicious, Stayman, Winesap and Arkansas. The flesh around the core is most usually involved, but water core may extend to the surface. The disease affects the fruit in the orchard and is usually worse in warm harvest seasons for fruit held too late on the trees. It may disappear in storage, but badly affected fruit is susceptible to breakdown.

Avocados. Some varieties of California avocado can be stored at 40°F for about 2 months. Fuerte, the most important commercial variety, becomes brown at 40° but stores well at 45°³. Florida varieties such as Lula and Taylor can be held at 37° to 42° for 4 weeks, and other varieties stored better at 42 to 48°^{4, 5}.

Bananas. Bananas are another fruit susceptible to chilling injury, and just what temperature they can withstand depends a lot on the variety and maturity. The Gros Michel variety is the important one in this country. Chilling by 54.6°F was reported although other work showed that it took 14 days at 52° or 9 days at 51° for chilling⁶. Some varieties like Lacatan and Congo must be held at 58 to 60° and Giant Governor at 56 to 58° to avoid chilling. On the other hand, in Australia the Cavendish variety withstood 4 days at 50° with no chilling injury except delay in ripening. From a practical standpoint avoiding temperatures below 55° would be advisable. Chilling injury causes delayed ripening, brown color of the skin, and under extreme cases failure of the flesh to soften, lack of flavor or off-flavor.

Cranberries. A large portion of the cranberry crop is held in common air-cooled storage at the cranberry bogs during the fall and early winter until it is needed for processing or shipment to market in the fresh state. For long

storage, cranberries keep best "in the chaff" before sorting and cleaning. They can be held about 3 months and the most desirable temperatures are 36 to 40°F whether attained in air-cooled storages or by refrigeration¹. Varieties and maturities differ in storage life. End-rot, a fungus disease, develops at low temperature in storage. Low-temperature breakdown develops in cranberries held more than 2 to 3 weeks at 32°. The affected berries are rubbery, with their flesh permeated with red pigment from the skin.

Grapefruit. Florida grapefruit can be stored about 4 weeks at 31 to 32°F. These low temperatures are necessary to keep phomopsis stem-end rot in check. If used directly from storage the fruit can be held as long as 2 months but will decay quickly after removal from storage. Pitting of the skin is brought on by temperatures below 50° and the fruit becomes susceptible to decay at the pitted areas. Off-flavors, brown discoloration of the skin, and internal browning eventually develop at temperatures lower than 50°.

Texas grapefruit from selected groves not infected with phomopsis stem-end rot can be stored 2 to 3 months at 50 to 55°F and still have adequate market life. At these temperatures pitting and other forms of chilling injury are not factors, but the fruit will develop a yellow color. The recommended temperature for the storage of California grapefruit is 60°⁷. Decay is not such a serious problem in California fruit as it is in Florida and Texas fruit, for the fruit is grown in a drier climate not so conducive to infections by decay organisms in the grove. The use of fungicidal washes such as borax and sodium ortho-phenylphenate and biphenyl-treated liners are helpful when decay is a problem.

Grapes. Vinifera, or California grapes, are stored from harvest in October until March and April and sometimes as late as June. The best storage varieties are Emperor, Ohanez (Almeria), Calmeria, a new variety, and Ribier (Alphonse Lavallee). The best storage temperatures are 30 to 31°F with humidities of 88 to 92 per cent. An essential part of grape storage is fumigation of the grapes with sulfur dioxide prior to storage, using about 1 per cent concentration for 20 to 30 minutes, and refumigation in storage every week to 10 days with 0.25 per cent by volume. The sulfur dioxide treatment against decay necessitates storing grapes in a room alone, for other foodstuffs are injured by sulfur dioxide. A means of getting rid of the sulfur dioxide by exhausting it to the outside air or absorbing it in a water spray is also advisable. Eastern grapes are of a different species, are less firm and decay-resistant, and have a poorer storage life. They can be stored about 1 to 2 months. They are injured by sulfur dioxide and this treatment is not used on them. They should be stored at 31 to 32° at 80 to 85 per cent humidity.

Lemons. Lemons are stored at the packing house before packing and are

shipped to meet market demands. Storage of 1 to 4 months is common. The fruit is usually harvested before it is full yellow and ranges from green to light green and "silver" in color. The dark-green fruit usually has the longest storage life. Storage of lemons after they reach the market is hazardous, for they may be close to the end of their storage life and were shipped for that reason. The best storage temperatures for lemons are 55 to 58°F with a humidity of 85 to 90 per cent.

Oranges. Florida oranges should be stored at 30 to 32°F and 85 to 90 per cent humidity. Valencia oranges can be held 8 to 10 weeks under these conditions. Treatment with borax or sodium ortho-phenylphenate and use of biphenyl-treated liners or boxes are recommended for their value in preventing storage decay. Low-temperature injury to Florida oranges by 30 to 32° has not been a serious factor. California oranges, because they are apparently more subject to rind disorders than Florida fruit, are stored at 35 to 37°F. The Washington Navel variety will keep 8 weeks and Valencia 6 to 8 weeks⁷. After 8 weeks, blue and green molds and rind pitting may occur.

Pears. Pears are somewhat exacting in their storage requirements. Above all else, pears must be harvested before they are too mature. The most serious storage trouble of pears, core breakdown, is due to overmaturity. Pressure-test readings for picking maturity have been worked out for each variety. Quick cooling to the storage temperature and holding at 29 to 31°F are recommended. The best ripening temperature for pears after storage is 65°. At 75 to 80° they may fail to soften and will not develop good color and flavor. The storage life for important varieties of pears is as follows¹: Bartlett 1 to 3 months, depending on where grown; Hardy 2 to 3 months; Comice 2 to 3 months; Bosc 3 to 3½ months; Kieffer 2 to 3 months; Anjou 5 to 6 months; and Winter Nelis 6 to 7 months.

Beans. Green beans can be held for only 8 to 10 days. When they are stored at 40°F or 32°, chilling injury in the form of pitting and russetting develops in about 3 to 5 days¹. Russetting may not appear until the beans are removed from storage and kept where it is warm.

Cabbage. Cabbage is an important storage crop in the Northern States where air-cooled storages are operated to hold temperatures of 32 to 35°F¹. The longest keeping varieties, which belong to the Danish Ballhead class, can be held 3 to 4 months until the early crop from the South reaches the market. The early crop has a limited storage life of 3 to 6 weeks.

Carrots. Many carrots are stored in caves or cellars in the northern states, where cold temperatures can be maintained by ventilation. High humidity is necessary to prevent drying out. The carrots should be topped before storage and injured stock should be removed to prevent growth of rots. Cold storage at 32°F and 90 to 95 per cent humidity would probably

do a better job than common storage, but the cost is not often justified. With almost a year-round production of carrots for the market, storage is usually employed for holding a crop grown for that purpose until it can be processed.

Cucumbers. Cucumbers are a short-lived vegetable at best and cannot be expected to keep over 2 weeks. Storage at 32°F is not possible, because severe pitting will take place in 6 days and slight injury in 2 days. Cucumbers keep the longest at 45 to 50°, but they ripen at these temperatures and the color changes from green to yellow.

Onions. Many onions are placed in common storage in the northern states during the winter months, where they are held until about March. Part of the crop is put in cold storage for longer holding. The best storage varieties are Creole and Australian Brown and Yellow, Red and White Globe types. Sweet Spanish types are only fair keepers. Only well-cured onions should be stored. Rainy cold harvest seasons are not conducive to good storage quality. Storage troubles are rot, usually neck rot caused by *Botrytis*, sprouting and root growth. High humidities favor root growth and decay, and high temperatures induce sprouting and favor decay. The best storage conditions are 32°F and low humidity (70 to 75 per cent). If good air circulation is provided and the onions are stacked so that air can reach them, higher humidities (85 to 88 per cent) have been satisfactory for well-cured onions.

Potatoes. The fall, or late-crop of potatoes goes into common storage for the most part. They are cooled by ventilation with cool outside air. The potatoes are cooled slowly enough to provide good temperatures and humidities for healing cuts and bruises, before they are cooled to holding temperatures of 38 to 40°F, which are maintained until spring weather comes. They are usually stored in bulk in large bins. The potato has some peculiarities that should be recognized for good storage. First, it can heal wounds if given a chance. Not much new periderm will form at temperatures below 55°, and low humidities also are harmful. Second, potatoes if held at cold temperatures increase in sugar content in storage; some increase takes place at 40°F but it is much more at 32 or 36°. If potatoes have become sweet, they can be made to lose sugar by holding them a week or more at 70° or higher. During this period, some of the sugar is reconverted to starch. Manufacturers of potato chips and French fried potatoes must be sure that the potatoes they use have not accumulated sugar, for if they have the product becomes objectionably brown when cooked. Potatoes for chip making and French frying should be stored at 50°. In fact, from the standpoint of highest quality for all purposes, storage at 50 to 60°F is better than storage at lower temperatures, but sprouting may limit storage life to 3 to 4 months, depending on variety. The best storage temperature gives a

compromise between quality and length of storage period. From a practical standpoint, potatoes are stored for general use at 36 to 40° in common storage, and as they move into marketing channels they are subjected to much higher temperatures, which help to make them better to eat. Potatoes for special purposes such as chip making are held at 50 to 55°; thus some storage life is sacrificed and more sprouting is accepted. Use of chemical sprout inhibitors and selection of late-sprouting varieties may make higher storage temperatures more practical.

Sweet Potatoes. Sweet potatoes should go through a curing period at 85°F and 90 to 95 per cent humidity for about 10 days after digging in order to heal any cuts and abrasions that would soon become infected and decayed. Curing is done in the sweet-potato storage house by use of heat. After curing is finished, the temperature is lowered to 55 to 60° F or as near these temperatures as ventilation with outside air will accomplish. Sweet potatoes suffer chilling injury if exposed to temperatures below 55°. Symptoms of chilling injury are susceptibility to decay, poor texture and flavor and failure to synthesize provitamin A in storage. The Porto Rico is most resistant to chilling injury, and the Big Stem Jersey, Little Stem Jersey, Orange Little Stem and Maryland Golden the most sensitive. Sweet-potatoes can be stored 4 to 6 months at 55 to 60°¹.

Frozen Fruits and Vegetables

The storage of frozen fruits and vegetables is usually done after processing. However, occasionally the raw product is frozen to preserve it for future canning, freezing, juicing or manufacture. Berries are frequently frozen "dry" in field containers and dumped into boxes or barrels for later use, cranberries are handled in a similar manner and the freezing of peaches whole prior to canning has been proposed as a means of lengthening storage life. Vegetables require blanching before freezing; consequently freezer storage of the raw product is not feasible. Freezer storage calls for freezing quickly at 0°F or lower with high air velocity and storage at 0 to -10°F.

Eggs

The best storage conditions for shell eggs call for a uniform temperature in the range of 29 to 31°F with a humidity of 85 to 92 per cent^{8, 9}. Since eggs freeze at about 28° good temperature control is essential. With adequate air circulation humidities higher than 90 per cent can be used satisfactorily. The humidity should be held just below the point at which mold is likely to grow. If good quality eggs are stored properly, they have a maximum storage life of 8 to 9 months and will retain fresh flavor and high quality for 4 to 5 months in storage. Only eggs which are clean, sound, and at least Grade A quality should be put into storage for extended periods.

They should be packed in clean containers and packaging materials, with the large end of the egg up. Refrigeration is the best method known to preserve the quality of egg. Eggs deteriorate in quality through chemical changes that go on, through the action of bacteria and molds, and may lose quality by the absorption of odors from dirty containers or eggs, or of odors in the storage room. Strong odors from other storage commodities like onions, garlic, cabbage, potatoes, citrus and apples may damage the delicate flavor of eggs. For this reason eggs are usually stored in cold-storage rooms set aside for this purpose. During the storage period, the air space in eggs increases in size by evaporation of moisture. Net weight losses of 5 per cent in about 9 months have been reported¹⁰. The white becomes thinner and eventually loses its opalescence, and in 6 or 7 months it may develop a yellow tinge, which deepens with longer storage. As an egg ages, the yolk tends to take up water from the white and becomes larger while the yolk membrane weakens, thus giving the yolk a more flattened or spread-out shape. The yolk membrane weakens slowly, but, if the eggs are fresh when stored, they can be separated even after 11 month's storage.

Most of the eggs placed in cold storage are shell-treated. The process is not designed in any way as a substitute for cold storage, but rather to improve the keeping quality of the eggs that are stored. This process consists of dipping eggs for a few seconds in a bath of colorless, odorless, and tasteless mineral oil having a viscosity of 50 to 60 Saybolt seconds at 100°F. The oil partially closes the pores in the shell and thus lessens the loss of carbon dioxide and moisture from the egg. The egg shell must be dry, since oil will not adhere to a wet shell. The temperature of the oils should be higher than the temperature of the egg. For best quality, eggs should be dipped within 12 to 24 hours after laying. Thermostabilization or heat treating shell eggs to stabilize the white and kill the embryo is another method of prolonging storage life¹¹. The most common cause of bacterial spoilage is the storage of dirty or improperly cleaned eggs. Improper washing of eggs may add contamination even though surface dirt is removed and certainly no washing process is known that will remove organisms which have gained entrance through the pores of the shell to the interior contents of the egg. Unless it is known that the eggs have been washed properly, storage of washed eggs is not recommended. Condensation of moisture on the surface of eggs can cause serious contamination and eggs should therefore be protected from exposure to warm moist air when removed from storage. Considerable mold growth takes place on eggs in storage if the humidity at the shell surface is 96 per cent or higher and a slight growth may take place at 90 to 94 per cent, but it will not be objectionable, except for long storage. If good air circulation is employed, 87 to 92 per cent humidity is safe, but if forced air circulation is not provided, a humidity of about 85 per cent is recommen-

ded. If the eggs have been oiled, that is treated with mineral oil, humidities above 85 per cent are not required.

Freezing is a common method of preserving egg magma for future use. Koonz¹² estimated that in 1951 about 89 per cent of the eggs produced were used as shell eggs, and about 6 per cent were used as frozen or liquid eggs. The balance of the production was used in the dried form and for hatching. Eggs may be frozen in the natural proportion of yolks and whites or frozen after separation. Since frozen and thawed egg yolk becomes gummy in consistency special treatment is required. Sugar or salt is added in amounts of 5 to 10 per cent. Eggs are usually frozen in 30-pound containers and should be frozen quickly and held at 0°F or lower.

Milk

Fluid milk is extremely perishable, because it is an excellent medium for the growth of bacteria. The relation of temperature and time to bacteria development in milk is given in Table 10-7¹³. Quick cooling to a temperature of 50°F or less is necessary to prevent excessive multiplication of bacteria even during a short holding period (24 hours), and low temperature (about 32°) is required for longer storage. The freezing point of milk from eight markets averaged 31.03°F ranging from 31.00 to 31.06°¹⁴. The accepted practice is to cool milk immediately to remove the animal heat before it is transported to central bottling plants. The practice of handling milk in tank trucks has grown rapidly, and mechanically refrigerated milk coolers are used for cooling milk as it comes from the milkers before it is transferred to the tank trucks. Milk is generally held at the bottling plant only until it can be pasteurized and packaged for delivery, usually about a day. Here the milk is kept cold and is re-chilled to 50° or below after pasteurizing and held at 40° or lower temperatures.

The question often is asked how long can fresh milk be stored? Tests on

TABLE 10-7.* GROWTH OF BACTERIA IN MILK IN RELATION TO TEMPERATURE AND TIME

°F	Bacteria per milliliter			
	24 hr	48 hr	96 hr	168 hr
32	2,400	2,100	1,850	1,400
39	2,500	3,600	218,000	4,200,000
46	3,100	12,000	1,480,000	—
50	11,600	540,000	—	—
60	180,000	28,000,000	—	—
86	1,400,000,000	—	—	—

* Adapted from chapt. 10, "Refrig. Data Book," 4th ed.³

milk held at 44°F, considered to be the temperature of most home refrigerators, indicated that 4 days was about the limit before off flavors developed in some of the samples¹⁴. In 7 days the average quality was poor. An unclean flavor was the most predominant characteristic and the evidence indicated that it was not due to bacteria. Fermented and acid flavors were less predominate and these flavors were considered to be due to bacterial growth. Milk held at 33° for 7 days had better flavor than that held at 44°. Recent tests with homogenized, pasteurized milk indicated it could be held at 33° for 2 to 6 weeks without affecting the flavor¹⁵. In some samples bacterial growth was so high in 3 weeks that off-flavors were detected. Storage life at 40° rarely exceeded 14 days. Off-flavors of stored milk were unlike those of milk held at room temperatures and were classed as "stale," "unclean," "cheesy" and "bitter" and were not always related to bacterial content. Objectionable off-flavors were detected in most cases before the bacterial count reached 500,000 per ml. Samples of milk from the same dairies held at least 6 weeks in freezer storage at -20°F had good flavor after thawing. The solids settled out, and shaking before use was required. Other workers have found that chocolate milk did not separate objectionably upon thawing even after 380 days' freezer storage at 0°F and they found that the addition of sucrose to homogenized pasteurized milk, $\frac{1}{2}$ part to 2 parts per 100 parts of milk, prevented separation in thawing in milk held 185 days at -10°¹⁶. With the higher amount of sucrose oxidation flavors were delayed for 100 days. Milk without added sucrose had a limit of 100 days' storage without separation when thawed and of 75 days without oxidation flavor.

Grains and Seeds

The storage of grains and seeds calls for protection against damage by insects, rodents, microorganisms and heating brought on by germination or the action of bacteria¹⁷. Estimates indicate that insects destroy at least 5 per cent of the world production of cereal grains. Loss of stored wheat in the Great Plains region may be as high as 10 per cent in a season and in the deep South corn in storage may be destroyed at a rate of 9 per cent per month by insects. Some insects devour at least their own weight in a week. Also they do indirect damage, causing grain to heat and give off moisture which favors molds and musty odors. Insect infestations cause lowering of grades and impairment of milling quality. Grain crops in the South become infested with insects in the field, but in the Corn Belt and Great Plains northward, field infestation is rare. Seeds of legumes such as beans, peas, cowpeas, and others are invariably infested with weevils in the field, so the grower must be ready to prevent further damage in storage. Other sources of infestation are the storage structure itself and grains and seeds left in storage or in nearby storages. Where field infestation is a factor, as in the

South, an early harvest is imperative to prevent serious inroads by insects. Loss of stored grain by rodents is estimated to amount to 1 per cent or more. Conservative estimates indicate that fungi and bacteria cause a loss of between 1 and 2 per cent of the world's grain production and their activities cause even greater waste in added costs for drying, storing, lowering of grade and untimely marketing¹⁸.

The most important single factor in the storage of grains and seeds is their moisture content. Insect development is discouraged by low moisture content and so is mold and bacterial activity. Under storage conditions similar to those in Nebraska, wheat, oats, shelled corn and similar grains can be stored for a year (not for seed use) with little loss if their moisture content does not exceed 13 per cent. Soybeans should have a lower moisture content, no more than 11 per cent, for long storage. Moisture contents 1 or 2 per cent lower than these are needed if the grain or seed is to be planted. Ear corn can have 20 per cent moisture if harvested in cool weather and stored in well ventilated cribs in the northern states. Safe storage is aided if the ears are freed from cracked kernels and foreign matter which provide food for insects and obstruct air movement through the pile of grain. The grain may require drying before storage. Batch or continuous dryers are used for this purpose. Drying in the bin is less efficient but can be accomplished by forcing air through the bin, preferably heated air. Some provision for air circulation through the bin is desirable to cool the grain rapidly and to maintain uniform temperatures and carry away moisture from the grain.

Storages should protect the grain or seeds from rain, snow and ground moisture, and they should be rodent-proof and insect proof and tight enough for fumigation. Steel bins which are tight and easy to clean, are best for small grains or other seeds. Wooden bins must be sprayed before use to kill insects and steel bins may require spraying around the door where insects are concealed. A $2\frac{1}{2}$ per cent solution of DDT, TDE, or methoxychlor by weight as emulsions or water suspension or 5 per cent piperonyl butoxide and $\frac{1}{2}$ per cent pyrethrins by weight as an emulsion should be applied at the rate of 2 gallons per 1000 square feet.

Farm-stored small grains should be fumigated within 2 weeks after they are put in bins in the South and within 6 weeks in the central part of the country. In the North fumigation may not be necessary except as an insurance. One fumigation may be enough in the Northern and Central States, but in the South inspection is necessary every 2 to 4 weeks and refumigation should be done if needed.

Fumigants and dosages for treating grains are given in Table 10-8¹⁹. Other fumigants are also in use. The surface of the grain in the bin should be covered with a coarse spray of the fumigant as uniformly as possible.

TABLE 10-8.* FUMIGANTS AND DOSAGES FOR THE TREATMENT OF GRAIN STORED IN WOODEN FARM BINS^a

Fumigant	Dosage per 1,000 bushels of—		
	Small grains except sorghums	Sorghums	Corn
	(gal)	(gal)	(gal)
Carbon tetrachloride.....	5	8	6
4 parts carbon tetrachloride + 1 part carbon disulfide ^b	3	8	6
1 part carbon tetrachloride + 3 parts ethylene dichloride ^b	6	10	6
19 parts carbon tetrachloride + 1 part ethylene dibromide.....	3	8	6

^a In steel bins the dosages may be reduced 50% for small grains and 20% for corn and grain sorghums.

^b The addition of 5% by volume of ethylene dibromide improves the killing of insects of immature stages in grain.

* From U. S. Dept. of Agr. Yearbook 1951¹⁹.

Plastic-lined hoses are necessary to resist the action of carbon tetrachloride. Application should be made in the cool part of the day when the wind is not blowing to minimize the loss of the fumigant. Fumigation of grain in elevator storages is simpler than in farm bins because elevators are usually tighter and the fumigant can be introduced into the grain stream as the elevator bins are filled. Dosages given in Table 10-8 for steel bins will be adequate for elevators.

Rice is commonly infested in the field by the rice weevil and other insects, and should be fumigated soon after stored. The fumigants for small grains given in Table 10-8 can be used. Rice is high in moisture when harvested and must be dried before it is stored in bins. Rough rice stored in bags in warehouses can be fumigated efficiently with hydrocyanic acid or methyl bromide at a dosage of 1.5 pounds per 1,000 cubic feet if the warehouses are tight enough to hold the fumigant for 24 hours. Soybeans stored in farm-type bins rarely become infested with insects, but occasionally bran beetles occur in high-moisture beans, which can be fumigated like small grains. Heating of soybeans in deep poorly ventilated bins may take place if the the beans are not dry when stored. Storing in shallow bins or on the floor until they are dry is recommended. If the soybeans are sacked, the piles of sacks should be open²⁰.

Dry beans should not be accepted for storage if their moisture content exceeds 17 per cent²¹. The insects causing most damage to beans and cowpeas are bean weevil, cowpea weevil, Indian meal moth, tobacco moth and almond moth²². Fumigation for at least 24 hours with methyl bromide or

chloropicrin in a gas-tight warehouse , freight or refrigerator car or under a gas tight tarpaulin is recommended. Heating the seeds to 145°F for 10 minutes is another method of killing the insects.

The many details of grain storage cannot be covered in this short treatise. Additional information can be obtained by consulting the references and of special interest is a recent monograph on storage of cereal grains and their products¹⁸.

Meat, Poultry and Fish

For long storage of meat, poultry and fish, freezer storage must be used. In general temperatures of −10 to 0°F and a humidity of 90 to 95 per cent are recommended. The storage life is less for pork, lamb, veal, poultry and fish than for beef (Table 10-9). The storage life for fresh meats varies from 3 to 5 days for pork, to as long as 8 or 10 weeks for finished beef loins and ribs from prime or choice grade dressed carcasses. The liver, heart and tongue of most animals and the giblets of poultry are extremely perishable and should not be stored unfrozen.

Refrigeration plays an extremely important part in the preservation of meat. As soon as the animal is slaughtered the warm carcass, about 100°F in temperature, should be chilled promptly to an internal ham or round temperature of 40° or below within 18 to 24 hours²³. Hanging the carcasses to leave air spaces between them is essential. Humidities of 85 to 90 are desirable in the coolers and the holding rooms. After the meat has been chilled, it may be transferred to a holding room held at 32 to 34° or processed or cut up at once for distribution. Beef, if it is a “good” grade or better, is customarily aged for 10 to 15 days in the chill room to improve

TABLE 10-9.* RECOMMENDED STORAGE TEMPERATURES, RELATIVE HUMIDITIES, APPROXIMATE STORAGE LIFE AND AVERAGE FREEZING TEMPERATURES OF MEAT, POULTRY AND FISH

Commodity	Temp (°F)	Relative humidity (%)	Approximate storage life	Average freezing point (°F)
Beef, fresh.	32 to 34	88 to 92	1 to 10 weeks	28 to 29
frozen.	−10 to 0	90 to 95	9 to 12 months	—
Pork, fresh.	32 to 34	85 to 90	3 to 5 days	28 to 29
frozen.	−10 to 0	90 to 95	6 to 8 months	—
Lamb, fresh.	32 to 34	85 to 90	5 to 7 days	28 to 29
frozen.	−10 to 0	90 to 95	8 to 10 months	—
Veal.	32 to 34	90 to 95	5 to 7 days	28 to 29
Poultry, fresh.	32	85 to 90	1 week	—
frozen.	−10 to 0	90 to 95	5 to 6 months	—
Fish, fresh.	32 to 35 ^a	90 to 95	5 to 20 days	—
frozen.	−10 to 0	90 to 95	8 to 10 months	—

^a A small amount of finely crushed ice keeps fish moist and cool and melts slowly at this temperature.
* Adapted from chapt. 19, “Refrig. Data Book,” table 1⁸.

tenderness and taste, during which time a temperature of about 35° is employed. Lamb and mutton are not aged more than about 6 or 7 days. The problem in storing fresh meat is prevention of bacterial spoilage, development of slime or molds on the surface of the meats often brought on by high humidities, and excessive drying out and loss of color promoted by low humidities and too much air circulation.

At slaughter, normal muscle tissue from healthy animals is generally free from bacteria. When evisceration is not prompt, penetration, extension, and development even in regions as remote as the hip joint may result. Unsanitary implements or practices in dressing the carcass may promote spoilage. Bacteria may enter or penetrate beef by direct extension of surface colonies and by extension and locomotion along moist surfaces or tubes such as the lymph vessels, nerve sheaths and blood vessels²⁴. The chief source of superficial beef microflora was found to be the hair and hide of the slaughtered animal²⁵. Only about 1 per cent of the bacteria found on the carcass were organisms viable at 30°F, whereas 99 per cent were viable at 68°F. One of the major advantages of rapid chilling is the prevention of rapid multiplication of microorganisms which will grow at warm temperatures but not at lower ones. In chilling tests, carcasses of beef have shown an increase in temperature in the center of the round, from 99.7°F at time of kill to 103° an hour later even though the beef was held at 32 to 35°F²⁶. This phenomenon is due to the glycogen-lactic acid reaction in meat which brings about a change in pH of the muscles from 7.2 to 5.7 to 6.2. Excessive moisture on the surface of meats, whatever its cause promotes bacterial growth. On beef and lamb cuts, bacteria multiply as well at 36 to 38°F on a moist surface as they do in drier cuts at 45 to 50°. Excessive drying causes oxidation of the red colored hemoglobin into methemoglobin.

The bright red color of beef most desired is related to the glycogen content and pH of the muscle. These factors are part of a complex carbohydrate mechanism which in turn is concerned with O₂ uptake of muscle hemoglobin. If an animal has been under condition of stress just prior to slaughter in which glycogen content of the blood was reduced, dark colored meat may be the result²⁵. A resting muscle has a neutral reaction and normally contains a considerable amount of glycogen. After death the reaction becomes acid due to the production of lactic acid and glycogen disappears in amount equivalent to the lactic acid produced²⁶. The first direct consequence is that the pH of the muscle steadily falls from the time circulation stops. In full rigor a pH of about 5.6 is reached. In muscles poor in glycogen, full rigor may set in without change in pH. The removal of adenosine triphosphate (ATP) is the immediate cause of stiffening of muscle in rigor. The fall in pH hastens the destruction of ATP. Low pH, associated with high glycogen is desired for its effects on color, texture, and keeping qualities of most meat products.

Poultry, like other meats, must be chilled quickly to 35°F, and this may be accomplished by cooling in cold air at about 32°, or in cold brine or in an ice slush. The last method is most commonly used and is preferable to air cooling since drying out of the flesh is minimized and it can be done in about half the time in air, or in 3 or 4 hours¹². Broilers and friers are often shipped in iced packages to nearby markets. This method of preservation has advantages in preventing drying out and keeping the temperature close to 32°.

Fish has long been shipped or stored for short periods in iced containers. More recently a combination of iced containers and mechanically refrigerated storage rooms has been used to hold fish prior to shipment or processing. This practice is to be recommended. Using a small amount of ice, only enough to keep the fish moist, prevents the formation of water and leaching of minerals from the fish²⁷.

Freezing storage of meat, poultry and fish is usually done after packaging. The kind of packaging material used will be important in preventing moisture loss from the product, the cause of "freezer burn," and the development of off-flavors. Poultry and fillets of fish are often protected by various types of film wraps that are good moisture vapor barriers and slow down oxidation. "Pliofilm," "Cryovac" film, moisture-proof cellophane, and polyethylene film are commonly used for packaging ready to cook poultry to be frozen. Meats and poultry are usually wrapped and packed in fiberboard or wooden boxes before freezing. Dressed poultry should receive initial rapid freezing which will result in freezing the carcasses weighing less than eight pounds in from 30 to 40 hours. The approximate highest temperatures which will attain this result under average to most favorable conditions are -10°F with circulated air and -20°F with still air; however, freezing temperatures of -20 to -40°F are desirable. Wetting the wooden boxes is of benefit in preventing drying of the product and preserving the natural color. There is a growing volume of meat sold after it is cut into 10 to 14 ounce pieces, wrapped in a moisture-vapor resistant material and frozen.

When fish is frozen whole it is often glazed with ice after freezing by dipping it in water. Reglazing in storage is accomplished by spraying the frozen fish with water. This may be done every 3 or 4 weeks if the freezer storage air is of low humidity. The thin layer of ice forms a protective barrier against moisture loss and oxidation of the oil or fat of the fish. Quick freezing is essential for long storage life, and high velocity air of about -20°F is employed for freezing.

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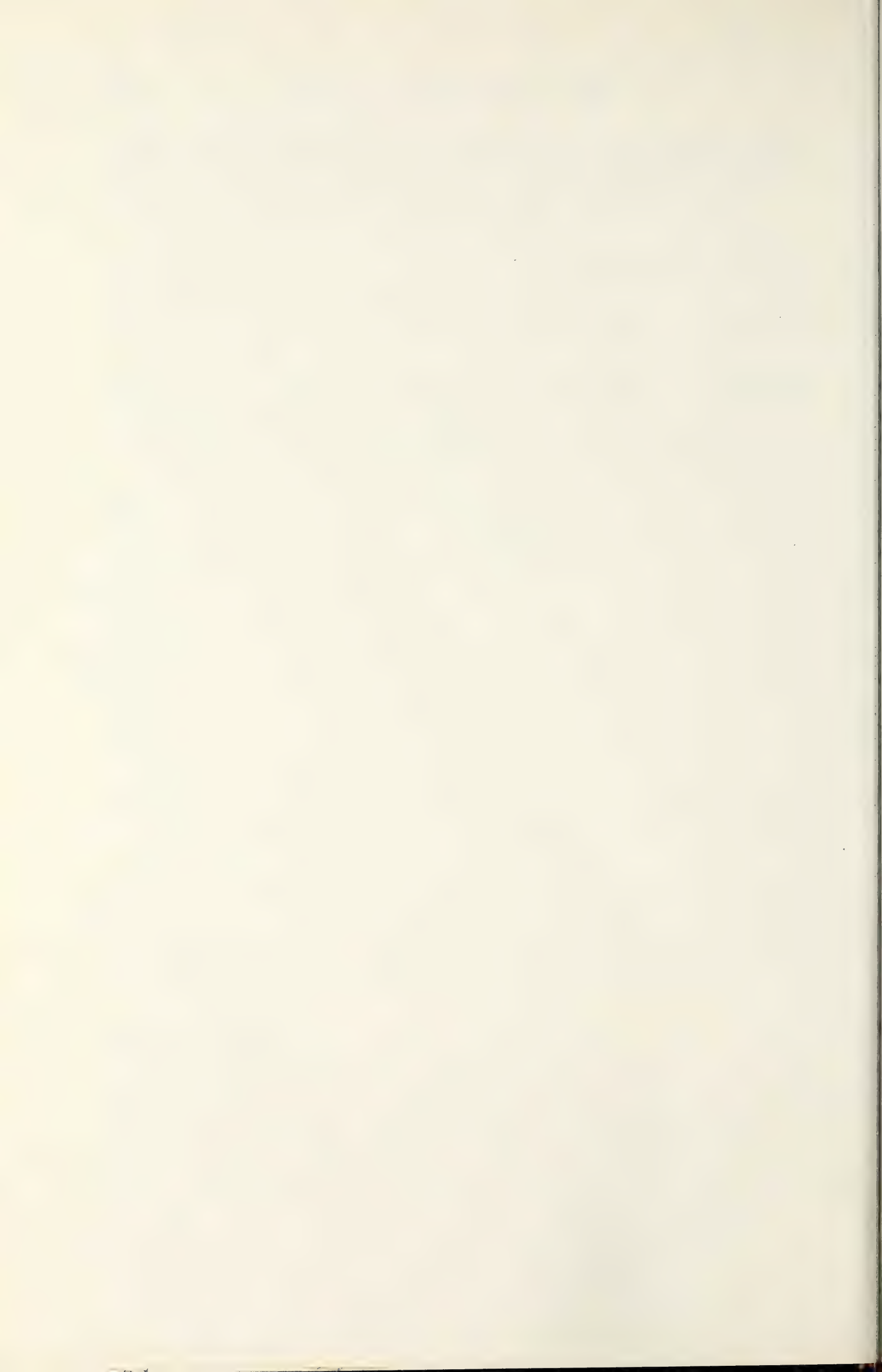
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11. FOOD PRESERVATION

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Introduction

The food industry is America's largest business. At retail prices the value is estimated at \$60,000,000,000 a year. Food processing establishments constitute 28 per cent of all industrial plants. Employees in the food and dependent industries earn about \$15,000,000,000 a year.

The average American family spends roughly 35 per cent of its income on food alone. The contribution of food preservation to greater food variety, to better health and to human happiness is incalculable.

Retrospect

Since earliest recorded history man has preserved food. Probably the first method of food preservation was by drying in the sun and wind. In colder countries snow, ice and freezing were used. Since even primitive peoples know how to make salt from sea water, it is certain that salting of food was practiced by early man. The use of fire and smoke to dry, partly cook, and thus preserve fish and meats is also a practice of long standing. Through the ages there has been a gradual but steady improvement in man's foods—both in variety and quality. Many have been continuously prepared and preserved in more convenient ways. This has been brought about largely by new and improved practices of food preservation.

It should be recalled that food canning was not discovered until 1810 by Appert in France. Even so, canned foods were of little importance for another sixty years—that is, until Pasteur and other scientists showed that the cause of food spoilage was microorganisms—yeasts, molds and bacteria. Pasteur was likewise one of the earliest investigators to demonstrate the connection between microorganisms and certain diseases of man, animals and plants. Of course, his greatest contribution to food preservation was

the demonstration that heat destroys microorganisms and thus prevents spoilage—hence the term “pasteurization.” Earlier it had been thought that the air or oxygen was the chief cause of food spoilage.

Much of our present knowledge of food preservation is traditional, that is, the facts were adduced through generations of trial and error. Thus, it was discovered that cereal grains must be fully ripe when harvested and that unless they are protected against moisture, they will mold. Although freezing as a means of keeping perishable foods has long been known, only recently, with the development of modern packaging materials, have frozen foods reached their present popularity. Dehydrated foods, especially vegetables, were of very poor quality until after 1920 when the necessity of strict moisture and enzyme control was recognized. Very recent improvements in dried fruits have been effected by the use of epoxides, such as propylene oxide. In this case, moisture contents of 24 to 35 per cent are perfectly safe with resultant far better palatability and ease of utilization as food. Wine and beer are ancient beverages, but the development of our huge fruit-juice and carbonated beverage industries waited for new technology to reach their present importance. One has only to trace the development of the tin can from the early handmade tin cannisters, through the period of the hole-in-cap containers of the 1900 era, to the present open top technologically perfect steel-tin container which is used each year to package billions of pounds of foods for our tables all over the world. Glass technology has not stood still either. Today, we have clean, transparent, strong, light-weight jars and bottles for our foods and beverages. It must be recalled that the huge home-canning operations carried on in millions of homes owe their success and safety to the glass container. We must call to mind also the frozen foods industry—barely 25 years old—which has attained an importance nearly equal to canning in bringing to our tables a great variety of ready-to-cook foods at all seasons. Furthermore, we have seen the trend change from frozen food lockers to individual home freezers; thus, adding greater comfort, convenience and food variety for our people.

Frozen foods were made possible by advances in engineering technology in refrigeration, the construction of small freezing units, refrigerated cars and trucks, improved refrigerated storages, and finally, efficient sales cabinets, home refrigerators and freezing cabinets. Thus food technology has not been static—in fact, advances and improvements have followed one another with such speed that it has been difficult to keep up with them. In 1920 there was no profession known as “food technologist.” Today, the nation has perhaps 6,000 skilled technologists and engineers concerned with food research, technology, production and merchandizing. Today, food preservation plays a most important role in the technological progress and greatness of the United States.

Why Preserve Food?

Obviously, the main reasons are: (1) to extend the period of consumption and marketing of the fresh fruit, vegetable or other food, (2) to give variety to the diet, (3) to make local produce available to everybody, (4) to give the consumer a wider choice in the selection of his food items, (5) to make it possible to properly feed our armed forces, and (6) to maintain a stock-pile of preserved goods for emergencies.

The industry stabilizes food costs, makes possible the marketing of produce grown in areas far from the large centers of population, gives employment to many persons in the production, handling and marketing of the goods, and greatly simplifies food purchasing in the interest of good nutrition, health and satisfaction.

Some natural foods need no form of preservation. Examples are grains, legumes, cereals, nuts, seeds and honey. Others, like potatoes, apples, citrus, root vegetables, butter, fat, honey, and wine keep for several months. Still others receive no further preservation after processing except perhaps the avoidance of moisture. Examples of these are flour, starch, manufactured cereal products, cheese, sugar, candy, chocolate, dried fruits, salted and dried meats and fish, and certain baked cereal products.

Causes of Deterioration, Decay and Spoilage

The short storage life of some foods is attributed to many causes and varies with the several commodities. Thus, the principal agent causing decay in acid fruits and eggs is mold (fungus), with yeasts and bacteria of secondary importance. In low-acid foods (pH higher than 4.5), the principal causes of spoilage are bacteria. The optimal range of pH values for bacterial growth is 6.0-7.2. In this range we find many vegetables, cereals, flesh foods, legumes, eggs, nuts and dairy products. While yeasts are involved mainly with the fermentation of acid products, they may occur as well on fish, salt vegetables, dairy and saccharine products. Molds and yeasts cause only "moldy," "fermenting," sour or yeasty odors. They are at most, only slightly proteolytic. On the other hand, bacteria can cause the whole gamut of deteriorative changes—from a "lack of characteristic odor," sourness and taint, to one of profound putrefaction. The latter condition is usually the result of protein breakdown by anaerobic bacteria. The biochemical activities of bacteria range from very slight to very marked. Seldom is only one species of microorganism present in food. Many species may be present on a vegetable or a fish, some of which will remain totally inactive. Others, will greatly increase in numbers, gain the ascendancy over other competitive microorganisms, and produce certain well-recognized biochemical and physical changes in the food. These may be characterized by odor, taste, texture and color changes, by the formation of such chemical end products

as lactic, acetic or butyric acids, ammonia, trimethylamine, indol, and sulfur compounds. Often, there are several microorganisms present. Their varying biochemical activities produce a vast mixture of chemical substances and may cause extensive physical changes in the food, such as softening of the tissues, offensive odors and possibly color changes.

It is not a well known fact that most of the food poisoning bacteria (*Salmonella*, *Brucella*, *Shigella* and *Staphylococci*) usually produce few outward changes when growing on meats, vegetables, dairy, poultry and fish products. Thus, odor (or even taste) is not a very useful criterion in judging the safety of a suspected food. Indeed, if the odor is that of spoilage, there is a good chance that the "food poisoning" bacteria are absent.

Milk sours naturally due to the growth of lactic acid bacteria, fruit juices ferment due to yeasts, fruits and cereal flours mold, meats and fish undergo various types of souring and protein decomposition due to bacteria. Thus, in foods we find a varying pattern of spoilage types. Varying methods of control (or preservation) are indicated, such as pasteurization or canning for milk and fruit juices, drying for cereals and flours, cold storage or freezing for fruits, and either drying, freezing or canning meats and fish.

Enzyme Changes

Enzymic changes cause many types of quality deterioration in foods. Of course, enzymes also produce desirable characteristics such as ripening of meats by proteolytic enzymes, diastatic conversion of cereal starches to sugars, juice clarification by pectolytic enzymes and the softening action of invertase in fondant used for candies.

Enzymes are particularly active and troublesome in fruits and vegetables and their products. The browning of plant tissue, production of unnatural flavors in stored and frozen foods, the fat oxidations in butter and oils, and the gelation and separation in frozen orange concentrates are examples of unwanted enzymic changes which may occur in foods.

Enzymes, as well as microorganisms, must be controlled by food preservation procedures such as pasteurization, canning, chemical treatments (sulfur dioxide, inert gases, salt, and ascorbic acid). For example, recent discoveries have demonstrated that more severe processing temperatures are required to destroy the oxidative and pectolytic enzymes in cucumber pickles and citrus juices than for the complete destruction of microorganisms.

Thus, food preservation methods as here outlined, seek by destroying microorganisms, insects and enzymes, to preserve the food in a fresh, dehydrated, frozen or chemically treated state so that it can be used later with safety and convenience and still be attractive and palatable.

Insect Control

Insects and their larvae are important food destroyers. Much attention has been given to the protection of foods against insect contamination. These measures include chemical fumigation, heat and electrical treatments and vacuumization in addition to final protective packaging, ultrasonic vibrations, high-speed electrons and various electrolytic and irradiation technics.

Unit Operation Factors

The unit operation concept so commonly used in the engineering field has been used to classify the several operations used in food preservation. Thus, Food Industries* defines a unit operation as, "A method by which an intentional or controllable change of form or place of a food material or ingredient is effected." The fourteen major unit operations in food factories, listed without regard to relative importance are:

- | | |
|--------------------|-------------------------|
| (1) Cleaning | (8) Forming |
| (2) Coating | (9) Heat exchanging |
| (3) Controlling | (10) Materials handling |
| (4) Decorating | (11) Mixing |
| (5) Disintegrating | (12) Packaging |
| (6) Drying | (13) Pumping |
| (7) Evaporating | (14) Separating |

While all of these operations are not used in many food preserving processes, mention of this concept is useful to the food processor. For example, heat exchanging is an operation common to many industries. Thus, a general knowledge of this particular subject is applicable in many areas of industry.

METHODS OF FOOD PRESERVATION

A convenient outline showing the interrelationships of the several methods of food preservation follows. An attempt has been made in this chapter to follow these operations (or unit processes) in some detail. Naturally, there will be some overlapping because in most cases food preservation consists of the use of several methods, or combinations of methods. Thus, freezing uses cold to retard the growth of microorganisms, yet without correct and adequate packaging and storage, the method would be useless. Similarly, smoking fish utilizes several principles of preservation, i.e., drying, pasteurization, hardening of the surface, chemical preservation from the smoke, and sometimes brining to firm the flesh and reduce the water content.

* Name changed to *Food Engineering*, published by McGraw-Hill Publishing Co., New York.

Food Preservation

Application of Heat		Cooking Pasteurizing Canning Preserving and jelly making
Application of cold		Cold storage or refrigeration (above 32°F) Freezing
Drying	Evaporation or sun-drying Dehydration	Outdoor heat and wind Artificial drying, kiln, tunnel, spray; roller (steam); vacuum drying; dehydro-freezing
Fermentation		Alcoholic Acetic Lactic
Chemical agents	Sugar Salt Acids Spices (mustard) Sulfur dioxide Alcohol Epoxides and fumigants (methyl bromide) Benzoates, propionates, nitrites Inert gases Stabilizers, antioxidants and antibiotics Hydrogenation	
Physical action	Vacuumization Concentration Pressure Fats and oils, paraffin, water glass Packaging films Filtration Distillation Comminution Ultraviolet and other irradiations	

The Application Of Heat

Cooking. Strictly speaking, cooking is merely a temporary means of holding food for a few days. Yet, among primitive peoples, and even where refrigeration facilities are lacking, it is useful. By re-cooking meats every day or two, they may be kept from spoilage for a week or more.

Cooking can also be used in conjunction with freezing as in ready-cooked frozen foods. Meats and fish which are to be dried may also be cooked

(boiled or steamed) previous to drying. Blanching (scalding) of leafy vegetables might be construed as cooking. In this case, the cooking is useful in destroying enzymes which would render the food valueless after freezing or dehydrating.

Pasteurizing. Historically, pasteurization meant the heating of foods, especially wine and fruit juices, to such a degree that would prevent fermentation or spoilage. Since about 1900, when milk pasteurization was introduced, the term has come to mean "safe," that is, the temperature of pasteurization destroys the nonsporulating bacteria and viruses capable of causing disease in man. Regulations in various cities and states call for fluid milk to be pasteurized by heating to at least 142.5°F for 30 minutes. The usual temperature now used is 145°F. This is sufficient to destroy the tubercle bacillus, as well as the causative agents of brucellosis, typhoid, salmonella, septic sore throat, diphtheria, cholera, scarlet fever and poliomyelitis. Pasteurization of milk does not destroy the anthrax bacillus which is a spore former. While pasteurization inactivates neither the toxin of *Clostridium botulinum* nor the bacillus itself, botulism from fresh milk and either fresh or pasteurized fruit juices and fruit products (pH values below 4.5) is, at best, extremely rare. It is axiomatic that foods are processed at the gentlest heat treatment consistent with safety and keeping quality.

Typical pasteurization temperatures for fruit juices such as grape, apple and citrus juices are 145 to 165°F for 15 to 30 minutes. There is a modern trend to use flash pasteurization temperatures such as 190°F for 1 minute, 212°F for 10 to 15 seconds or 250°F for 1 to 3 seconds, or even less. The actual sterilizing values of some of these short time, high temperature processes for fruit juices have not been carefully determined. However, in practice these procedures have proved superior to the older "holding" methods in several ways. They produce a product superior in color and flavor, the process is continuous, which saves time, and costs are reduced. A number of very efficient commercial pasteurizers are now available and in use in the food industries. Batch pasteurization belongs in the past.

It was stated before that the temperatures required for destroying enzymes were often higher than those required to sterilize fruit products. Enzyme inactivation is no doubt related to denaturation of the enzyme proteins. Pectinesterase is destroyed in citrus juices at approximately 190°F, held for 1 minute. Similar temperatures are required for the destruction of the peroxidase in cucumbers and probably other vegetables. Therefore, it is now customary to pasteurize all juices and acid foods at temperatures not less than 190°F for 30 to 90 seconds in order to definitely eliminate enzymes as a source of deterioration. Since frozen orange concentrates have not been heat-treated, the pectolytic enzymes present have caused considerable gelation and liquid phase separation after several months of storage

at 0°F. In order to overcome this defect, many processors are now flash pasteurizing orange juice at 160°F or higher to reduce enzyme activity to a point where gelation does not occur.

Pasteurization is effective in greatly improving the quality of dried fruits such as figs, dates and peaches. Microorganisms and insects are readily destroyed at moist heat temperatures from 150 to 170°F. Steam is usually used as a source of moist heat.

Canning. Canning is simply a method of food preservation where ready-to-eat food is hermetically sealed in a container, subjected to a thermal treatment sufficient to prevent spoilage, and then cooled. Normally, the food in the glass or tin container is sterile, but not necessarily so. A few bacteria, especially spore-forming ones, may persist even after the thermal treatment process. Such canned foods have been called "commercially sterile." This simply means that the canned foods in question will keep under normal storage conditions. Bacteria are most likely to survive in canned meats, fish, cream-style sweet corn, cereal products and possibly a few other low-acid foods where the heat transfer is largely by conduction and where a more severe process would seriously injure the quality of the food.

While Appert discovered the *art* of canning in 1810, the *science* of canning remained undeveloped for another fifty years or until Pasteur found the true relationship between microorganisms and food spoilage, and showed that heated foods, if not recontaminated, would keep indefinitely. Both the tin can and the glass jar with suitable closure admirably served this purpose. However, until about 1900, when both cans and jars were greatly improved and our knowledge of bacterial spores and their destruction by heat was applied to the canning industry, progress had been relatively slow. These developments were soon followed by the perfection of the present open-top sanitary can which could be mass produced. Can enamels were also perfected which greatly extended the use of tin cans to such foods as fruits, seafoods and nonacid vegetables which often corroded or discolored the metal container. Through extensive research by the can and glass manufacturers, the canning trade associations, and universities, the canning industry has reached its present high level of scientific and technical greatness.

Tin Cans. Tin cans are composed of approximately 99 per cent steel base with 1 per-cent (more or less) pure tin. Until a few years ago, the steel plate was dipped in molten tin to give a very thin continuous coating. However, the present use of electrolytic tin plate has largely replaced the dipped plate with a saving of 100 to 300 per cent in the use of the scarce tin metal. The shift to electrolytic tin plate during World War II was largely responsible for can manufacturers tripling their former production from an equal quantity of tin. For an excellent description of the fabrication of the tin

can, and use of enamels and food processing procedures, reference should be made to "The Canned Food Reference Manual" published by The American Can Company.*

Cans are made in several sizes to meet public demands. Sizes are expressed in inches and sixteenths of an inch. Thus, the so-called No. 2 can is designated "307 x 409", i.e., $3\frac{7}{16}$ inch in diameter by exactly 4 inches in height.

Can Enamels. Can enamels or lacquers oven-baked on the interior of the tin plate before the can is formed, serve several purposes, the main ones being increased attractiveness of both food and container. These enamels consist of varnishes or lacquers of oleoresins, vinyl, wax, phenolic condensation products, and other inert plastic materials. Can linings must be nontoxic and free from odors and flavors. The composition of individual can enamels is known only to the manufacturer. Most linings are applied to the flat tin-plate before forming. It is baked in ovens.

The baked film must adhere firmly to the tin plate, yet must be sufficiently elastic to prevent fracture during manufacture and subsequent handling. It must likewise be resistant to the temperatures used in retorting (thermal treatment). Furthermore, the enamel films must be totally resistant to the food in the can. Thus, the several sanitary or standard fruit enamels must be acid-resistant, and inert to pigments. Enamels are used on tin plate for highly pigmented fruits and juices. This enamel prevents pigment bleaching and corrosion. Acid-metal reactions often form hydrogen gas which in turn bleaches the food and increases the partial pressure within the can. The end result may be a "hydrogen springer"—a defect usually resulting from a combination of long storage and high temperatures.

In "C" enamels, zinc oxide is incorporated in the film so that volatile sulfur compounds liberated from the food will be trapped before they can react with the container metals or contents to form brown or black sulfides. Zinc sulfide is white and is not noticeable in the can or food. No objection to the use of zinc compounds has been offered by the U. S. Food and Drug Administration. "C" enamel is used principally for such low-acid vegetables as peas, sweet corn, lima beans and spinach, and for meat products and seafoods. In the case of canned shrimp, for example, the quantity of zinc oxide used in the enamel might be several times greater than that used in cans for packing peas. Special enamels must be used for canning grape, apple and citrus juices and for wine and beer. During World War II German canners used cans of enameled steel plate containing no tin. These served in the emergency. Also, here in the United States much research on direct enameling on the steel base has shown that definite possibilities exist for further saving of tin. Some inert foods can be packed in such cans. Undoubtedly, further research will point the way for greater use of such containers.

* 100 Park Avenue, New York 17, N. Y.

A few food products such as grapefruit sections and juice, pears, applesauce, white cherries, and pineapple are packed in plain tin cans because of the bleaching effect of the can metals on the product. The lighter color is considered to be more attractive.

Generally speaking, enameled cans perforate (pinhole) more severely than those made from plain tin. The fruit acids seem to concentrate at the tiny flaws in the enamel and tin and may ultimately perforate the can. An electrolytic cell formed by the iron and tin components, corrodes the metals.

Since the tin can is a nonrigid container, it possesses certain advantages over glass, especially during heat treatment. The can may be hermetically sealed before undergoing sterilization. This is more difficult in the case of glass containers. The heat simply distends the can ends without affecting the seams. A good partial vacuum in the can, over 10 inches of mercury, materially reduces the pressure within the can during processing. Other advantages are light weight, ease and speed of manufacture, conveying, filling, sealing and handling. The can may become dented, but it does not rupture. Another advantage is that the can metals react promptly with headspace oxygen and thus aid in preventing surface discoloration, and off-tastes. This may also result in better retention of ascorbic acid and possibly other nutrients.

Aluminum Cans. Aluminum cans have been made without difficulty. They are in commercial use in Norway for fish products. Unless stiffening alloys are used, the aluminum plate is too pliable for rough handling. The seams spread and thus cause spoilage. In spite of considerable research in this country, aluminum cans have not proved successful. However, with cheaper metal and better alloy technology, there may yet be an application of aluminum containers in the food industry. The use of aluminum foil in food packaging has made tremendous headway in the past few years. It is particularly useful in packaging butter, margarine, candies and precooked frozen foods.

Glass Containers. Glass containers such as jars and bottles possess the obvious sales advantage of transparency. The customer likes to see what she buys. Hence, foods which are attractive are most often glass-packed. The glass container is now commercially available in many shapes, sizes and designs. Fundamentally, glass is an amorphous, transparent or translucent supercooled liquid composed of 70 to 75 per cent silica, 12 to 18 per cent of alkali oxides, 6 to 12 per cent of calcium and magnesium oxides in addition to aluminum, boric and sometimes other metallic oxides. Glass may be clear (flint glass), green of various shades, amber, blue, ruby, etc. For blanketing out ultraviolet light, ruby and amber glasses are best. The ingredients should be of high purity. The molten glass is formed into the

desired shapes and sizes by very ingenious automatic forming machines. Cooling is done very slowly in lehrs to give greater strength and to remove molecular strains. By modern technics glass containers are very light in weight, perfectly formed and extremely resistant to cracking from heat, cold, shock or pressure.

Well over a billion glass jars a year are used in home canning. It is well to recall that Appert used glass containers in his first successful canning experiments. While the filling and closing operations are somewhat slower than in the case of tin containers, modern speedy machines give uniformly satisfactory results. Of course, there are far fewer discoloration and corrosion problems in glass containers as compared to tin cans.

Closures. For glass containers, many types of closures are used. These include corks, metal caps or crowns, metal screw caps, molded caps, vacuum caps and lug caps. In some jars the glass lid rests upon a rubber ring and is held secure by a screw lid or a wire clamp during heat treatment. Following processing, the vacuum within the jar keeps the lid pulled down tightly on the jar top. In this type of closure, the jar vents during heat treatment. In most types of closure the gasket is fastened to the cap itself and is a part of it. Most commercial types of closure fully seal the container before the heat treatment, and in this respect are similar to the tin container. However, since the glass jar is rigid and does not expand appreciably during the heat treatment, the steam generated within the jar is likely to force off the lid after the steam in the retort or cooker has been shut off. Thus, it becomes necessary in processing sealed glass containers to introduce compressed air in the cooker so as to always maintain more pressure in the cooker than is generated within the jars themselves. An average process might produce an average internal pressure within the jar of 20 pounds per square inch. It would then be necessary to introduce about 25 pounds of air pressure in the cooker to prevent leaks, blown lids or even shattered jars. Since the market affords suitable equipment, glass container processing and its operation are relatively simple; no great problems exist in the sterilization of glass containers.

Crown caps are easily pressed on the bottles and make a very satisfactory closure. Corks are rarely used in the United States except for closing bottles of wines, cordials and pharmaceuticals. It is difficult to sterilize corks, even in boiling water or by use of chemicals. Crown caps, and similar cork liners, are often treated with paraffin or other finish to protect the food from direct contact with the cork. Treated paper, plastic or foil discs are also used as facing materials. After processing glass containers of liquids, the containers are often placed on their sides so as to allow the hot liquid to sterilize the closure.

Like tin cans, glass jars may be sealed in a vacuum chamber. Another

method of obtaining a good vacuum is by passing the open jar through a steam chamber which removes most of the headspace gases. The jar is sealed mechanically while still in the steam chamber. This method also serves to sterilize the lid at the same time. Glass containers must be cooled slowly in the cooker by admitting cool water slowly in order to condense the steam or water vapor in the jars and form a vacuum. Large tin cans such as No. 10's (holding 3 quarts) which are processed at temperatures above 212°F must be handled similar to glass containers or serious malformation of the can may result. Compared to small cans, large sizes are less able to resist stresses such as those produced by pressure and vacuum.

The principles of food canning are the same whether the operations are carried out in the home kitchen or in a large factory. In some respects the handling of each individual food is a little different. Generally speaking, the fruits, vegetables, meats, fowl and fish to be canned are trimmed or dressed, washed, cleaned and graded in the same way as for preparation for cooking. Most vegetables, except tomatoes and rhubarb are low-acid, i.e., they have a pH value of 4.5 or above. Extensive investigation, in addition to long cannery experience, has demonstrated the necessity of using temperatures in excess of 212°F in the thermal processing of these foods. Otherwise, sporulating bacteria may survive and cause spoilage. Furthermore, should *Clostridium botulinum* be present there is danger of the presence of toxin. At the present time, temperatures of 240°F are used for varying times of exposure, depending upon many factors, such as tightness or consistency of the pack, shape of pieces, presence of starch, size and shape of the container, initial temperature, partial vacuum within the container, degree of initial bacterial contamination and possibly other factors.

Processes for most canned foods have been carefully worked out by the National Canners Association and published in Bulletin 26-L. Recommended home canning processes may be found in the U. S. Department of Agriculture Farmers Bulletin 1762 or in the State Experiment Station Home Canning Bulletins.

Blanching. By blanching is meant the scalding or precooking of certain vegetables such as beets, carrots, spinach, asparagus, peas, snap beans and others. Fruits are usually not blanched for canning. The purpose of blanching is to reduce bulk and facilitate handling. It destroys enzymes (principally oxidase systems), aids in removing adherent soil, insects, surface gummy substances and microorganisms, sets the green chlorophyll color, and removes much of the tissue gas, including oxygen.

Some products are blanched in hot water or steam to facilitate peeling or dicing. It is claimed that blanching removes the "raw" flavor from certain foods such as peas, okra and beans. The blanching time varies with the vegetable species, also with the maturity. For example, tender peas may require only 2 minutes at 212°F, while more mature ones may require 5 min-

utes. Blanching is accomplished by exposure to either steam or hot water. The process removes varying percentages of water-soluble nutrients such as ascorbic acid, B-vitamins, sugars and minerals, but the losses are not serious. For this reason, the blanching operation is kept to the minimum time and temperature required to accomplish the enzyme destruction.

If the blanched vegetable is filled into the container promptly with added hot brine, further heating in an exhaust box is unnecessary to get a satisfactory vacuum in the can or jar.

Exhausting. Since air is one-fifth oxygen, air removal is synonymous with oxygen removal. In the sealed container the presence of oxygen is undesirable. A partial vacuum of at least 10 inches is desirable in canned food in order to decrease seam strain during processing, to eliminate much of the oxygen in the container, and to prevent springer formation. There are two methods of obtaining a vacuum; (1) heat exhaust and (2) mechanical vacuum. The heat exhaust is again accomplished in three ways; (1) hot filling, as in cream-style sweet corn, (2) by vacuum pump, and (3) passing through a steam exhaust box to raise the temperature of the contents to 140 to 160°F or even higher. All these methods greatly reduce the oxygen content of the headspace by scrubbing it out by means of water vapor. In both glass jars and tin cans "vapor-vacuum" sealing is sometimes used. By this method the container passes into a semi-enclosed atmosphere of steam just before sealing. The steam replaces much of the headspace gas, and later condenses causing a partial vacuum within the container. In most home-canning type glass jars, the seal is not completed until after the process. Thus, venting of gases from the jar continues during the thermal processing. Normally, this produces a vacuum of 18 to 23 inches.

There is a growing preference for "cold" or mechanical exhaust as against the old steam exhaust boxes. Of course, the temperature of the contents in the container must not exceed 120 to 130°F when a vacuum is "pulled," otherwise the liquid will boil out under the high exhaust.

Thermal Processing. As stated previously, acid foods below pH 4.5 are normally processed at temperatures below 212°F, thus eliminating the need for a steam pressure retort. Normally, temperatures of 190 to 200°F in the center of the can will suffice to prevent spoilage. Most juices are processed by a high temperature-short time procedure in various types of heat exchangers where the juice may reach temperatures of 200 to 260°F for 20 to five seconds. By cooling, the high rate of heat transfer makes it possible to heat the juice very rapidly to the temperature of the heating medium and to cool it almost as quickly to the temperature of the cooling medium.

Batch processing in either vertical or horizontal retorts is commonly used for products with a pH value above 4.5. Continuous cookers are great time savers but expense precludes their use except by large volume canners.

Heat transfer in canned foods takes place both by convection currents

and by conduction (particle to particle). Thus, with peas, peaches and whole or diced beets, the heat transfer is by convection, while in cream-style sweet corn, sliced beets, squash, meat and spinach, the mode of heating is by conduction. The latter foods require a severe heat process which may injure palatability. In some cases, heat-resistant spores may also escape destruction.

As stated before, individual foods require their own individual thermal process. In this short chapter it is impossible to give details for each fruit, vegetable or other food product. Manifestly, the rate at which heat penetrates into the food must be known. Copper-constantan thermocouples are usually used to determine the rate of heat penetration in cans of food. Similarly, the heat resistance of the bacteria capable of causing spoilage must also be known. From these data one can calculate an adequate thermal process. The thermal death time of spores can be determined in the laboratory by exposing them to certain temperatures for varying periods of time. Ingenious mechanical devices called thermoresistometers have been designed to carry on such studies accurately and quickly. The final step is to actually incubate processed cans of food containing the bacteria for several weeks. The most commonly used bacteria is a putrefactive spore forming, heat resistant anaerobe called "Organism 3679." Since the spores of this organism are more heat resistant than those of *Clostridium botulinum*, it is certain that thermal processes as worked out by this method are entirely safe. In fact, very few cases of botulism have been attributed to commercially canned foods for the past 25 years. On the other hand, home canning processes, which are much less carefully controlled have led to a number of botulism outbreaks and to a higher percentage of containers showing spoilage.

In canning, automatic controls play an important part in regulating the time, temperature, pressure, air and water flow, fill-in weight, etc. Automatic controls eliminate uncertainties and variations in the pack, increase output per unit, permit control within narrow limits, and save steam and water. Only the smallest and most backward plants now use manual controls. To err is human.

In operating pressure cookers (retorts), it is very important to eliminate air by "bleeding" valves, otherwise, indicated gauge pressure may be in error. Steam pressure-temperature relationships are accurate only if the retort is well vented and free of air. Temperature readings are usually more accurate than pressure readings. However, care must be taken to locate the thermometer bulbs in flowing steam and not in air pockets.

Since the initial temperature of the food is important in timing the process, care must be exercised to maintain a constant initial temperature before actual heat processing begins. Thus, recommended thermal processes for a

given food are always based on a certain minimum initial temperature, such as 140°F.

Cooling. This is a very important operation. Prompt cooling checks the destructive action of heat on tissue texture, color and flavor. Once the micro-organisms have been destroyed, there is no further need for heat. Water cooling is the method most commonly used. Either cold water is introduced directly into the retort cookers or the cans are removed from the cookers and cooled in "canals" in cold water running counter current to the can conveyer. In cooling glass containers, warm water is admitted to the retort followed by cold water to avoid breakage. However, modern glass containers are made of low-expansion glass and are remarkably resistant to breakage. It is advisable to cool food containers to 110 to 100°F so that there remains sufficient heat to dry the can or glass jar. Rapid and prompt cooling is especially important in pigmented and soft foods and in those whose flavor is seriously affected by severe heat. In foods that are difficult to render sterile, prompt cooling often causes spores to remain inactive. This is especially true of thermophilic bacteria.

Canned Food Storage. Depending upon the character of the product, many canned foods must be considered "semiperishable," i.e., the storage life is definitely limited. This is particularly true of pigmented berries, shrimp, citrus and highly acid foods. Prompt use, or storage at cool temperatures, is necessary if these products are to remain attractive and palatable. On the other hand, canned vegetables, meats, fowl and fish are very stable and may remain in good condition for several years, even at ordinary temperatures. Greater use of refrigeration is most desirable for the extended storage of canned foods. Of course, cost is often a decisive factor. Cranberries deteriorate so badly after canning that after the market has been satiated in the autumn months, further canning is done using only frozen berries. In this way, a good quality cranberry sauce is available all the year.

Warm storage of canned foods of all kinds is to be avoided—the canner or wholesaler should use the coolest space available—and even then, he should move his canned foods with the least delay possible.

Canned Food Defects. Discolorations of various kinds may be encountered—pigment fading and dark or brown discolorations. The can metals, tin and iron, sometimes react with fruit pigments. They also react with enclosed oxygen and produce a reduced condition within the sealed can. Oxygen disappears in sealed tin cans within a few days after sealing; it remains in glass containers much longer. Some of the oxygen reacts with the metals, but some may also react with the food itself and cause surface browning. In most cases the use of about 100 to 150 mg of ascorbic acid per pound effectively controls this kind of discoloration.

As stated previously, can enamels are very effective in preventing dis-

colorations and reaction of the food with the container. Sulfide discolorations are adequately controlled by the use of enamels containing zinc oxide. Contact with copper, lead or iron leads to a dark discoloration of the food. Thus, the first run of sweet corn through the canning line is usually discarded because of metal contamination from the long unused machinery. The sulfides originate during the processing through protein breakdown by heat.

Cans with distended ends are called "swells" or "springers" dependent upon the extent of the pressure within the can. This condition can be caused (1) by overfilling, (2) by gas-forming microorganisms or (3) by acid-metal reaction forming hydrogen gas. The latter condition usually takes place only after several months storage. Swells due to bacteria or yeasts occur most often shortly after canning. The high internal pressure may burst the can or glass jar.

"Flat sours" occur in products like tomato juice, sweet corn and other hard-to-sterilize vegetables. This condition is caused by thermophilic bacteria whose spores are extremely heat resistant. The organism produces organic acids but no gas—hence, the can ends remain "flat." Flat sours can be detected only by opening the container and examining the contents. Fortunately, flat sours are nontoxic. Lack of vacuum in a can or jar often indicates a leaky or faulty seam, sometimes due to worn chucks or other maladjustment. Dented cans show reduced vacuum but the contents are entirely edible. Off-flavors in canned foods may be the result of chlorophenols from water, spray or soil treatments, oils, fly sprays in the cannery and other causes.

Toughness of canned vegetables can often be traced to the use of hard water or salt containing considerable calcium.

The Application of Cold

Refrigeration (Cold Storage). Refrigeration as discussed under this heading is concerned with temperatures at or above 32°F. For centuries, the urgency of getting fresh vegetables and fruits to the market in good condition led to the establishment of near-by growing areas. It became customary to harvest the vegetables in the late afternoon or very early morning in order to place them on the market before wilting and deterioration took place. Later, in 1810–1820, ice as a means of extending storage through ice cooling came into general use. Mechanical refrigeration was used to a limited extent as early as 1890. Between 1910 and 1920 the use of refrigerated cars and trucks became established. This made the larger cities nearly independent of locally grown produce and encouraged the shipping of fresh foods from tropical climates and from far away areas of production. Refrigeration means foods of better quality, variety, and nutritive value.

Refrigerated trucks haul fresh milk for distances of 500 miles or even more. Meat is shipped from the Midwestern packing plants to the centers of population in refrigerated cars. Apples are stored for many months in cold storages, held at temperatures of 31 to 32°F. Nearly every city now boasts of one or more large refrigerated cold storages for all kinds of perishable foods such as shell eggs, fruit, root vegetables, nuts, candy, butter, cheese and even canned fruits. These storages have rooms with controlled temperature and humidity. There are now about 2,000 cold storage warehouses in the United States which are capable of handling between one and a half and two million carloads of refrigerated freight a year. Of course, these warehouses also have rooms at freezing temperatures for the purpose of holding frozen foods until marketed. They act as wholesale reservoirs for the retail trade.

Mode of Action of Cold. Nearly all microorganisms prefer growth temperatures of 65 to 100°F; thermophiles grow best at temperatures of 110 to 130°F while psychrophilic bacteria, such as many of those in the cold seas and soil, are active at temperatures as low as 32°F. Many of the latter types are relatively inactive biochemically. Cold suppresses the growth and activity of most microorganisms. *Salmonella* will not grow in foods below a temperature of 41°F. *Cl. botulinum* loses its ability to form spores below 50°F although the toxin is not destroyed at freezing temperatures. Cold, likewise greatly decreases enzyme activity but does not completely suppress it. Similarly, the rate of chemical reactions, such as oxidations, is also greatly retarded by cold. Within limits, the speed of a monomolecular reaction is decreased 100 per cent by a decrease in temperature of 18°F. Generally, there is a marked decrease in total numbers of bacteria in foods as a result of freezing. This decrease may be as great as 90 per cent. The non-sporulating bacteria are most sensitive to cold but the cocci and lactic acid bacteria are very resistant to freezing temperatures. Upon defrosting and liberation of nutritive juices, bacteria again grow rapidly. Since maturity in fruits is largely an enzymic activity, ripening can be greatly delayed by low temperature storage. For most fruits from temperate climates, temperatures of around 32°F are best, but for tropical fruits higher temperatures (usually above 40°F) must be used.

Since fruits and vegetables are living organisms, they respire giving off carbon dioxide and water. Energy is released in the form of heat. For example, strawberries held at 80°F evolve approximately 40,000 Btu's per ton per day; for strawberries held at 60°F, the energy released is 15,000 Btu's, while at 40°F, it is only 5,300 Btu's. Since the specific heats of fruits and vegetables also vary, these considerations are important in calculating the capacity of refrigerators. It is customary to precool warm produce before placing it in refrigerators or cars. A better keeping quality is thus assured. The heat

produced by the respiration of vegetable foods while they are being cooled, is directly proportional to the length of the cooling period. Since plant tissues produce carbon dioxide in the refrigerator, ventilation is desirable in order to avoid high concentrations which often impair flavor and color and hasten decomposition. On the other hand, small concentrations of carbon dioxide have over-all beneficial effects on certain fruits such as apples and pears. For example, McIntosh apples have been kept in perfect condition in an atmosphere containing 5 to 10 per cent carbon dioxide for eight months, whereas five or six months is considered the maximum keeping period.

Regulated humidity is very important in the cold storage of eggs and leafy vegetables to prevent desiccation. Excessive moisture leads to mold formation or bacterial spoilage. The most commonly used relative humidity is 80 to 90 per cent for fruits, vegetables, shell eggs and meats. For dried fruits and nuts the humidity is usually 50 per cent or lower.

The three standard types of mechanical refrigerator systems are compression, absorption and air. For detailed information on refrigerator design, refrigerants and freezing systems, the reader is urged to consult "The Refrigeration Data Book" and other references given at the end of this Chapter. Anhydrous ammonia is used extensively in large mechanical installations and methyl chloride, sulfur dioxide and "Freon" in domestic-type refrigerators. The commercial unit or *standard ton of refrigeration* is defined as the quantity of heat required to melt 2,000 pounds of pure ice into water at 32°F and thus extracting 228,000 Btu's per 24 hours. It should be recalled that the latent heat of liquefaction; i.e., the heat required to melt 1 pound of ice, is 144 Btu's.

In any discussion of refrigeration it must be kept in mind that cold is not only the method of choice in preserving many foods, but likewise is a most useful adjunct in the manufacture of ice cream, carbonated beverages, meat chilling, fruit juice concentrates, chocolate hardening and in fat and oil technology. It was a natural development that freezing should replace higher temperatures as soon as engineers had perfected suitable and economical freezers, storage and sales equipment. To the foresight and early work of Clarence Birdseye, we owe many of the present-day developments of our modern freezing industry.

Freezing. Because of the high content of water most foods freeze solidly at temperatures of 32 to 25°F. The latent heat of fusion varies from 30 Btu's per pound in bacon to 144 for water with intermediate values of 90 for poultry, 98 for eggs, 124 for milk and berries, and 134 for asparagus. The temperature of the food undergoing freezing remains nearly constant until the latter is completely frozen, after which time the temperature drops rapidly to that of the freezing medium. The specific heats of foods expressed

as Btu per pound vary with the food and especially with its water content. Thus, water is considered 1.0, beef fat 0.6, eggs 0.76, milk 0.90, and snap beans 0.92. The specific heat of many fruits and vegetables and lean meats is approximately halved after freezing. The basic principle of all rapid freezing is the speedy removal of heat from the food by any one of many standard methods.

- (1) Freezing in air; tunnel freezing.
- (2) Direct or indirect immersion.
- (3) Indirect contact, either single or multiple.
- (4) Spray or fog freezing.
- (5) Liquid air, nitrogen and carbon dioxide.

Freezing in still air is the slowest of all methods. By circulating the cold air the freezing rate is greatly accelerated. Air blast and tunnel freezers are the most commonly used types for food freezing. They are efficient, rapid and easily controlled.

Immersion of the product in the refrigerated brine or sirup is rapid and effective. It is used mainly for fish, poultry and meats. By using metal containers or waterproof films ("Pliofilm," "Cryovac" bags, and metal foils), the food is better protected and freezing rates are not impeded.

In indirect contact freezing the refrigerant is applied to a metal plate the reverse side of which comes in contact with the food or food package. There is usually a degree of compression to facilitate freezing. The multiplate freezer is a type of contact freezing. It utilizes calcium chloride brine held at a temperature of -45 to -50°F filled into hollow metal plates mounted in an insulated cabinet. The plates may be moved up and down by means of hydraulic pressure to make better contact with the food package. Normally, one pound packages freeze in about 45 to 65 minutes. Bulk products may also be frozen in metal pans with removable sides. The food is then packaged after freezing—usually in 5 or 10 pound cans or cartons. Storage of frozen food is normally at 0°F , or sometimes lower. Constant storage temperatures with little fluctuation are preferred to uneven temperatures. The latter forms large crystals through repeated freezing and thawing of small amounts of water in the food.

The spray or fog freezers depend upon the refrigerating action resulting from spraying cold brine or sirup against the sides and ends of the metal containers of food. This is usually carried out while on enclosed conveyor systems.

While progress is being made in the use of solid carbon dioxide and liquid air for freezing, lack of accurate controls and the danger which is involved have prevented their more extensive use. Carbon dioxide when subliming in air has a temperature of -110°F .

Eutectic ice is the solid formed when a mixture (by weight) of 76.7 per

cent water and 23.3 per cent salt is frozen. Eutectic ice melts at a temperature of -6°F . Three pounds of eutectic ice will give the equivalent refrigeration of 1 pound of solid carbon dioxide ("Dry Ice") at approximately 10 per cent of the cost of the latter. It is particularly useful in icing fish on board trawlers. It is usually used in the form of flake-ice.

Frozen Food Locker Plants. The first step in bringing frozen foods to the consumer was the city or village locker plant. Here, the customer could store his own or purchased frozen foods against his off-season needs. The locker was most popular in areas where fresh meats are available, i.e., the Central and Western parts of the country. In 1946 there were about 7,000 locker plants but the number has been slowly decreasing because of the development of the more convenient and efficient freezing cabinets or "deep freezes." The millions of home-type freezers in the United States have greatly increased the sales of commercially frozen foods. A still newer development in home freezers is the combination refrigerator-freezer. This has a much enlarged freezer compartment which furnishes ample storage space for many families.

The Freezing Process. As soon as the food reaches a temperature of 32°F , moisture on the surface freezes. The elapsed time consumed in freezing is dependent upon the difference in temperature between the food and the freezing medium. The more rapid the freezing, the better the results. There is less withdrawal of water from the cells and less damage to tissue structure. Quick freezing leaves most of the cells intact and in most cases reduces crystal size as compared with slow freezing. In slow freezing most ice crystals are found in the intercellular spaces of the tissues. As early as 1830 Goeppert indicated that freezing gradually extracts water from the cell colloids (protoplasm) and produces precipitation of proteins, concentration of salts and a partial collapse of the cell walls. All this results in dehydration, denaturation of proteins, and a more or less irreversibility of cell absorption upon defrosting. This irreversibility in structure is less marked in the case of flesh foods, but is very serious in fruits and vegetables. Sugar sirup exerts a distinctly protective action on the cell membranes when exposed to freezing. Dehydration is far more important in food freezing than was formerly thought. Recognition of this factor has led to such remedial measures as freezing in sirup, use of water vapor-resistant packaging films, and metal and glass containers for the freezing and storage of frozen foods. Especially, in the case of meats and fish, gradual, slow defrosting allows more of the free juices to be reabsorbed into the tissues. Of late years there has been less stress in industry on very rapid freezing. The extra costs involved are not entirely compensated for by a sufficiently improved quality, which will bring increased profit.

Enzymes and Microorganisms. While enzyme action is greatly slowed down at freezing temperatures, it is not entirely stopped. Thus, it is neces-

sary to blanch or precook many of the vegetables to be frozen. The blanch arrests the action of the oxidative and respiratory enzymes which are largely the cause of off odors, flavor and color deteriorations, and toughness. It also helps to remove dirt, soil, insects and microorganisms and to retain the green color of vegetables. Of course the wilting of raw vegetables also reduces bulk and facilitate packaging. The normal blanching time for peas varies from 1 minute at 212°F for young, tender peas, to 5 or 6 minutes for the lower (more mature) grades. Blanching often reduces the bacterial load on vegetables by as much as 90 per cent. Blanching may be accomplished by either steam or hot water. A further advantage of blanching vegetables is that lengthy cooking is not required after defrosting. This makes for an improved texture in the product when served.

Fruits are normally not blanched before freezing. They are simply graded, washed, drained and packaged. Similarly, meats and fish need only to be dressed and prepared for freezing. Eggs must be broken out and frozen with either 10 per cent sugar or 10 per cent salt. Sometimes 5 per cent glycerin is used. All these substances are added merely to serve as anticoagulants. Otherwise, the yolks become very "gummy" and are difficult to reconstitute. Salt yolks are used largely by the salad dressing industry. Seafoods, such as shrimp, oysters, clams and scallops freeze readily and retain their fresh quality. Lobsters, both true and spiny, as well as crabs lose some of their fresh quality on freezing due to protein denaturation.

For obvious reasons, some products do not freeze well, such as tomatoes, celery, egg plant, lettuce and watermelon. Frozen juices are readily frozen, either as single strength or as concentrated juices. Some freezers now give the juice a heat-treatment at 150 to 170°F to partially destroy pectolytic enzyme activity which often causes coagulation or separation in frozen orange juice.

Most poultry is dressed before freezing for the retail trade. While it has been amply demonstrated that undrawn poultry actually keeps better during frozen storage, such poultry is now used largely only by canners. For freezing, more and more of the poultry is being retailed as jointed pieces, or as boned chicken and turkey. By using "Cryovac" latex film on poultry, "freezer burn," or dehydration is entirely eliminated. Frozen, drawn birds have a much higher consumer appeal than the undrawn.

Precooked frozen foods have been packed for many years but because of the many technical difficulties involved, they have been slow in attaining consumer acceptance. At present, many excellent precooked foods are available. Examples are breaded shrimp and other seafoods, fish "sticks," chicken a la king, beef and lamb stews, bakery items, baked beans, pies, spaghetti and many others. The use of aluminum foil dishes for packaging has solved many packaging problems and has resulted in increased consumer acceptance.

Freezing destroys varying percentages of the bacteria present in foods. The reduction in some cases is over 90 per cent; in other cases it is much less. Nonspore-forming bacteria survive as well as those forming spores. There have been no reported outbreaks of botulism from frozen foods. Several investigators have demonstrated that *Trichinella spiralis* is destroyed in all stages at 0°F. Bacteria multiply rapidly if defrosted foods are held at room temperature. However, when held in the refrigerator below 50°F even the common pathogenic bacteria do not grow appreciably nor produce toxin. It is most desirable to defrost frozen foods by leaving them in the refrigerator until they are needed.

Quality and Nutritive Values. Special varieties of fruits and vegetables are prepared for freezing. Very often they are not the same varieties preferred for canning. Varieties, particularly suitable for freezing are described by the various State Agricultural Experiment Stations.

Quality control methods for frozen foods are very similar to those used in canning or dehydration. Strict attention must be given to grading, cleanliness, washing, freedom from rot, insects, grit and waste. Attractive packaging and accurate control of freezing and storage temperatures are very important. One of the *must* tests in preparing vegetables for freezing is the determination of enzyme activity in the blanched vegetable. Both the peroxidase (guaiacol) and the catalase (hydrogen peroxide) tests are used for ascertaining the adequacy of blanching in peas, snap beans, sweet corn, asparagus and okra. Moisture tests correlate well with specific gravity of peas, sweet corn and lima beans as a quality measurement. The lower quality peas are heavier and contain less water and more starch. Other useful quality determinations are alcohol insoluble solids, tenderometer test, color, starch and ascorbic acid. Details of these test procedures are given by Tressler and Evers in the references at the end of this Chapter.

Of course, packaging of frozen foods is extremely important. Many of the consumer criticisms have been traced to faulty packaging. Careful and continuous package inspection and examination are necessary if control of quality is to be maintained.

Microbiological quality is also of some significance in flesh and fish foods, as well as in precooked ones. Numbers of yeasts, molds and bacteria must be kept under control. High plate counts may mean poor quality or even seimispoiled raw products. pH determinations are also useful in many cases.

The nutritive value of frozen foods can be stated roughly as follows: The nutritive values of fresh, frozen and canned foods on the "as served" basis are very similar, though of course there are exceptions. Blanching removes some soluble sugars, proteins, minerals, and water-soluble vitamins such as ascorbic acid and thiamin. Blanching is a common procedure in

both freezing and canning. Peas and lima beans may lose 30 to 60 per cent of their ascorbic acid content in the freezing process. On the other hand, frozen concentrated citrus juices lose none of their ascorbic acid. Freezing has no effect on minerals and vitamins. Such losses as occur are incidental to processing such as in washing and blanching. Because of their acidity, frozen fruits retain a high percentage of their original ascorbic acid content. There is no significant loss of nutritive values in the freezing of fish, seafoods, meats and cereal products.

Drying

Drying is probably the most ancient method of food preservation. The term "dehydration" usually refers to artificial drying rather than the natural sun and wind desiccation. Cereal grains such as rice, barley, wheat and corn, as well as soybeans, beans, peas, lentils and fenugreek dry to a moisture content of 10 to 15 per cent in the field and normally require no further drying. Fruits which are high in sugar dry readily outdoors in warm, dry climates. Examples of such fruits are peaches, apricots, prunes, grapes, dates and figs. If the fruits are not peeled and halved, the skin is usually checked by use of a hot dip in water or lye (1 to 3 per cent). However, even in California the use of dehydrators is increasing because of superior control of temperature, humidity and air flow, as well as for speed in drying and for sanitary reasons.

Evaporated foods are usually considered to be those dried by means other than by sun drying. Examples are kiln-dried apple slices, potato starch and dried cranberries and blueberries.

The forced-draft tunnel is by far the most popular dehydrator. These units are equipped with high velocity fans with oil heating units of high capacity. The trays of prepared fruits and vegetables are trucked into one end of the tunnel and eventually removed from the other. Some dehydrators are operated as a continuous process. Often two or more primary tunnels are used to partially dehydrate the food and greatly reduce its bulk. A single secondary tunnel readily completes the dehydration. Naturally, at the start relatively high temperatures (155 to 170°F) can be used, but as the water content is reduced, the air temperature must also be reduced. For most dried fruits, the moisture content is reduced to 15 to 20 per cent while for vegetables a lower moisture per cent of 3.5 to 8.5 increases both flavor and storage quality.

Dehydrated eggs and powdered milk can be produced either in steam-heated drum dryers or by the spray-dry method, with or without vacuum, thereby lowering the temperature necessary for water removal. By reducing moisture content of these foods to very low levels, and storing in hermetically sealed drums or other containers, quality has been greatly improved.

Sulfur dioxide has been used traditionally for the sulfuring of apples, apricots, pears, peaches and sometimes figs and raisins. Flowers of sulfur are burned to obtain the sulfur dioxide fumes to which the fruit is exposed for periods of 30 minutes to several hours. Usually the treated fruit contains 3,000 ppm of sulfur dioxide but this amount soon decreases to 1,000 to 1,500 ppm. This concentration is sufficient for color and quality retention. Below 500 ppm most dehydrated fruits become brown and dark in color and stale in flavor. Such fruits cannot be salvaged. Sometimes, compressed sulfur dioxide, or even a short dip in a solution of sodium metabisulfite (3,000 ppm sulfur dioxide) is used in place of burning sulfur fumes. Since most fruits dry unevenly, it is customary to equalize the moisture content by storing in large bins. Here a moisture equilibrium is soon reached making it possible to package the dried fruits for storage or shipment.

The sulfur dioxide treatment not only prevents enzymic and oxidative discoloration but destroys insects as well. It aids in retaining ascorbic acid but destroys much of the thiamin. Sulfuring is normally carried out on the halved, pitted fruits. Apples for evaporation are sliced either as dried slices or as apple rings. Because of the decline in exports of all dried fruits their production has now been greatly curtailed.

Only during wars or emergencies have dehydrated vegetables been in demand. Those most desirable are potatoes, carrots, cabbage and onions. However, excellent dried sweet corn is now available and its increased use in the future can be assured. Dried, steam-cooked potatoes for convenient use in preparing mashed potatoes are gaining in popularity. Dried onion and garlic flakes, as well as powder, are now widely used for flavoring soups, catsup and other foods, and are used to some extent for home use. Other popular dehydrated foods are soup or soup bases, peppers, green peas, milk (whole and skimmed), cheese, gelatin desserts, spices and herbs. Until very lately, dehydrated fruit juices have not been satisfactory. However, experiments now under way at the Western Utilization Research Branch, Agr. Research Service, U.S.D.A., Albany, California, indicate that an orange powder of acceptable quality is now assured. While it is possible to prepare dehydrated meat and fish products, they have not found favor in this country.

Dehydro-freezing is another new method of combining dehydration and freezing to produce a good food product. By dehydrating peas, apricots or other foods to moisture content of 30 to 40 per cent and then freezing them, the bulk is reduced by nearly 100 per cent and the natural flavors and colors are well retained.

Evaporation under high vacuum is used for the production of soluble coffee, tea and orange powder. The use of high vacuum for food dehydration undoubtedly will see many applications in the future.

Fermentation

Fermentation may be considered a means of preservation of natural or manufactured saccharine foods. The more important types of fermentation are alcoholic, lactic and acetic. In the alcoholic type the sugars of fruit juices are transformed to alcohol by means of the enzymes of yeasts. Since yeasts do not normally ferment starch, it is necessary to transform the latter to sugar by either diastatic enzymes or by hydrolysis. Both methods are used. For example, in the manufacture of beer, the barley is allowed to steep and germinate in order to activate the enzymes in the germinating grain. Maltase, alpha- and beta-amylases and proteases are present. The grain is then dehydrated at low temperatures to about 5 per cent moisture and ground into barley "malt." Strains of *Saccharomyces cerevisiae* are used in the fermentation of beer. This malt now contains maltose and glucose, both of which are readily fermented. Beer usually contains from 3.5 to 5.5 per cent ethyl alcohol by volume. It is normally flash-pasteurized in order to prevent undesirable secondary fermentations.

Grape, apple and other fruit juices may be fermented by yeasts directly into wine. The alcohol content of unfortified wines depends upon the sugar content of the original juice but in most cases ranges from 9 to 15 per cent by volume. Light wines may be pasteurized at low temperature; white wines may be treated with sulfur dioxide. Fortified wines (20 per cent alcohol) do not require a heat treatment or preservative other than the alcohol present. A grape juice containing 18 per cent soluble solids in the original juice yields approximately 9 per cent alcohol by weight. The glass bottle is the preferred container for the marketing of both beer and wine. Of course, both beverages are also widely handled in casks as well. Tin cans with special interior enamels or wax linings have been developed for beer. However, canned beer is a strictly perishable beverage and keeps poorly unless refrigerated.

Milk remains fresh only a few hours at summer temperatures. If cooled promptly, the keeping quality is extended to two or three days. Cold, together with pasteurization, still further extends the life of sweet milk. Milk sours or "clabbers" readily due to the universal presence of *Streptococcus lactis*. The bacteria ferment the lactose into lactic acid causing the precipitation of curd (protein), and separation of whey. Such "sour" milk is entirely suitable for food and in many countries is a common article of diet. Of course, cheese is made from milk curds and after proper curing, keeps very well—especially in cold storage. Similarly, milk fat or butter may be separated from either fresh or soured milk—and possesses fair keeping quality under cold storage conditions.

Other important foods prepared by lactic fermentations are cucumber pickles, sauerkraut and other light salted vegetables. In the manufacture of salt stock for holding cucumbers until they can be further processed into

sweet pickles, relish or other products, a salt concentration of from 40 to 50 degrees salometer (10 to 12 per cent salt) is used. The salt prevents the growth of spoilage types of bacteria but allows the growth of lactobacilli and similar bacteria which ferment the sugars present to lactic acid. Preservation is attained by both salt and lactic acid. Low temperatures are also helpful in maintaining good quality in salt stock. Of course, the finished products are heat-preserved.

In the case of dill pickles made from fresh cucumbers, only 4 to 5 per cent salt is used for the cure. For preservation, dill pickles must be kept under refrigeration or canned.

Sauerkraut is made by subjecting shredded cabbage containing about 2½ per cent salt to a lactic acid fermentation. This transforms the sugar in the vegetable to lactic acid. However, in order to preserve sauerkraut it is necessary to either can or refrigerate it.

Saccharine juices may undergo acetous fermentation—a sort of secondary fermentation following the yeast conversion of sugar to alcohol. The enzymes of *Acetobacter*, in the presence of air, completely oxidize ethyl alcohol into acetic acid. Vinegar is a good example of this double fermentation. Vinegar may be made from grape juice, apple juice, malt syrup or from molasses or other saccharine liquid. The yeast fermentation to alcohol requires no air, hence better results are obtained under anaerobic conditions, such as occur in closed containers equipped with water-seals. The latter allow the carbon dioxide to escape but do not permit the entrance of air. Should *Acetobacter* be introduced before the alcoholic fermentation has been completed, they will transform a part of the alcohol to acetic acid. Since yeasts are sensitive to small amounts of this acid, the fermentation of sugar to alcohol is incomplete and will result in either under-strength vinegar or in a useless product containing sugars, alcohol and acetic acid.

At times, butyric acid is formed during the storage of butter or other fatty food products. Cold storage aids greatly in controlling butyric acid formation.

Microorganisms play a considerable role in the “curing” and preservation of some foods. Examples are the removal of glucose from egg whites by bacterial fermentation. Scotch cured herrings, fermented milks, various cheese types and anchovy products are other examples of controlled bacterial fermentations. The use of salt or even sodium benzoate or other chemical preservatives are also used to control food fermentations. “Cold storage, salting, chemical preservatives and antiseptic spices are other examples of controlling food fermentations.”

Chemical Preservatives

Sugar is by far the most important chemical food preservative. Sucrose from sugar cane or sugar beets, and glucose or corn sugar, are the main

sugars used in the food industries. Glucose is most often used as liquid "corn sirup solids" rather than the more expensive crystalline glucose. There is a growing tendency in industry toward the use of liquid sugar (sucrose) because transportation, handling and packaging costs are greatly reduced. Honey, which contains mainly invert sugar, can also be used like sugar.

Sugar preserves foods by inhibiting the growth of bacteria, yeasts and molds at concentrations of at least 65 per cent. It is believed that the preservation is effected by dehydration of the microorganisms due to osmotic pressure or plasmolysis. Naturally, to be effective the sugar must be in solution. Except in candies, candied peels and similar products, it is not possible to rely upon sugar alone for preservation. Although fruit preserves, jams, butters, jellies and sirups contain 65 to 70 per cent sugar, still it is customary to give these products a mild heat treatment in a sealed container often in addition to air removal by vacuum. These supplemental processes help control fermentation, surface molding and discoloration. Sugars are extensively used in canned and frozen fruits mostly for flavor and texture improvement rather than as a preservative. Final preservation is by heat or freezing.

Second in importance only to sugar, is salt. Salting, or salting combined with drying, is much used in the curing of meats, fish and some vegetables. Salt is antiseptic and while it does not destroy all bacteria, those causing spoilage are kept under control until the moisture content has been substantially reduced. Of course, the salt acts as a drying agent by the osmotic withdrawing of water. In salted, dried fish and meats bacterial and enzymic actions are arrested. However, fats and oils are not preserved by salt and drying, but actually become rancid at an accelerated rate. Hence, most fish species which are dry salted, are lean fish.

In the dry salt processing of fish the dressed or split eviscerated fish are packed in casks or tanks with alternate layers of salt. The fish must remain in the strong brine 80 to 90 degrees salometer (21 to 23 per cent salt by weight) until fully cured. The curing may take two or three weeks. Fish are often given a dip in a 5 to 10 per cent salt brine to harden the surface somewhat so that the texture is improved. The brine also "cuts" the slime and removes many bacteria. Brined fillets can be handled and packaged with greater ease and with less breaking up. Salt is likewise used in connection with the smoking of fish. In most cases the fish are light-salted before smoking. Examples are herrings and finnan haddie. Certain types of canned sardines and anchovies are brined previous to smoking and canning.

Salted meats were once a staple article of diet in the United States. At present, salt pork, ham, bacon, corned and dried salted beef constitute the main commercial products. Meat is cured today largely because tradi-

tionally we have become accustomed to these products. Salt is used primarily for its flavor rather than for its preservative action. Hence mild cures have become increasingly popular. Improved sanitation and refrigeration make the use of salt less necessary. Salt brine, containing sodium nitrate and sodium nitrite, is pumped into hams through an artery before the ham is placed in brine. Pumping greatly reduces the chance of "bone sour" in the deeper layers of flesh. The principal agents used in meat during curing are salt, sugar and sodium nitrate and sodium nitrite. Sugar is added for flavor primarily, but it also aids in setting up a reducing condition which favors good color development. The sodium nitrate-sodium nitrite compounds are color-fixation agents and are bacteriostatic. Cured hams contain from 3 to 5 per cent salt with a moisture content of 66 to 70 per cent.

To give a specific formula, corned beef is normally cured in a brine containing 8 to 10 pounds of salt to 100 pounds of beef. The salt is rubbed well into the meat. To 4 gallons of brine are added 1 to 2 pounds of sugar, 2 ounces of saltpeter and sometimes 2 ounces of baking soda. The curing process requires from 30 to 40 days.

In the preparation of dried corned beef, the corned beef is simply drained, dried and smoked.

The preparations of salt stock (salt cured cucumbers) and sauerkraut have been discussed under "fermentation." In these products, salt simply makes conditions favorable for the growth of lactic acid fermentation bacteria. The combination of salt (10 to 12 per cent) plus lactic acid (0.6 to 0.8 per cent) is sufficient to prevent spoilage.

Vegetables such as onions, peppers, green beans, cabbage and cauliflower are usually preserved in a strong brine containing approximately 15 per cent salt (60 degree salometer). At this high salt concentration, little or no fermentation occurs, but preservation is none the less complete. Should these vegetables be allowed to undergo a lactic acid fermentation at 40 degree salometer brine (10 per cent salt), the texture would be seriously injured. Most garden vegetables can be easily preserved by brining. Brined sweet corn is a particularly fine product—yet a totally neglected one.

Acids. Acids are rarely used alone in the preservation of foods. Acetic acid or vinegar is by far the most commonly used acid. It is the principal preserving agent in salad dressings, mayonnaise, sauerkraut, some types of pickles and relishes, marinated herring, potato salad, and in pickled beets and pears. The preserving action is not due to the H-ions alone. Acetates and propionates in themselves possess marked bactericidal and fungicidal properties. Thus, sodium propionate when added to flour in concentrations as low as 0.15 per cent, effectively prevents bread molding. It is much used in humid climates.

Mayonnaise usually contains 6 to 7 per cent distilled vinegar (5 per cent)

by weight. Occasionally, lemon juice, citric or lactic acids are used to acidify foods. Distilled vinegar is normally preferred to fruit or malt vinegars in the manufacture of food products.

Both hydrochloric and ascorbic acid dips are effective in preventing brown discoloration of cut peaches, pears and apples. However, there is some doubt as to the legality of the use of the former. Sorbic acid as a preservative agent has recently been tentatively approved for use in foods. This acid, $\text{CH}_3\cdot\text{CH}:\text{CH}\cdot\text{CH}:\text{CH}\cdot\text{COOH}$ is an excellent fungistat. Its action is due largely to the inhibition of the dehydrogenase enzyme system in molds. Recommended uses are in cheeses or cheese wrappers, fruit juices and sirups, pickles, margarine, and candies. In curing cucumbers it permits normal lactic fermentation while preventing growth of molds and yeasts.

Spices. The value of spices as food preservatives has been over-rated. Primarily, spices are used for seasoning. Far from acting as preservatives, they have often been implicated as causes of food spoilage and deterioration through their bacteria, mold, enzyme and tannin content. While it is true that both oil of clove and oil of cinnamon possess some antiseptic value, little reliance should be placed on spices as useful aids to food preservation. The sterilization of whole spices by the use of ethylene oxide or other suitable fumigant, greatly improves their sanitary quality. There is a growing tendency in the food industries to use spice oils, extracts and emulsions in place of either whole or ground spices. Advantages are obvious.

Mustard acts as a preservative through its content of allyl isothiocyanate or oil of mustard. In prepared mustard, this oil, together with added vinegar, prevents spoilage. Mustard oil is useful in preserving apple and grape juice.

Sulfur Dioxide. Sulfur dioxide, either in the form of gas or soluble sulfite salts aids in the preservation of dried fruits and vegetables. At concentrations of 2,000 to 3,000 ppm color is well retained and growth of insects, molds and yeasts is discouraged. Sulfur dioxide acts as an enzyme poison and greatly improves the appearance of dried fruits and vegetables.

Another recent application of sulfur dioxide is in the treatment of cut and sliced fresh apples and potatoes for the bakery and restaurant trade. The treated products (2,000 to 3,000 ppm sulfur dioxide) will retain a good quality at least a week or so at cold storage temperatures (32 to 40°F).

Alcohol. Alcohol finds little use as a food preservative. Yet, it is the prime preservative in the keeping of distilled and vinous liquors, and hard cider. In the case of beer, pasteurization, carbon dioxide, bottling or canning and cold storage, are also factors in flavor retention during storage. Certain extracts such as lemon and vanilla owe their keeping quality to their alcohol content. When used as an antiseptic, a 50 per cent ethyl alcohol is far more effective than a stronger solution.

Epoxides. Propylene and ethylene oxides are used to prevent the souring and fermentation of such semidry fruits as dates, figs, raisins and apricots. It is possible to market these packaged dried fruits at the high moisture contents of 28 to 35 per cent. This improves the customer acceptance of these fruits by giving better flavor and color retention, softer texture and good insect control. The volatile liquid is atomized directly into the package or carton before sealing. Propylene oxide gradually changes to the harmless propylene glycol.

Fumigants. As fumigants, methyl bromide, ethylene oxide-carbon dioxide mixtures, hydrocyanic acid and ethyl formate are very useful and effective against insect pests. They are used both at atmospheric pressure and under vacuum to improve penetration.

Benzoates and Nitrates. Salts of benzoic acid, such as sodium benzoate, have been used in many foods as preservatives. The usual concentration is 0.1 per cent. This substance is bacteriostatic rather than bactericidal. When use in fresh fruit juices it inhibits fermentation for several days or weeks—depending upon the storage temperature. Benzoates are more effective in acid foods. Soda fountain sirups, pickle relishes, and margarine are examples of food to which benzoates are often added. It is no longer permissible to use benzoates in tomato catsup. Use of benzoates in foods in Canada is prohibited but nitrites can be used in some foods.

Nitrites, such as sodium or potassium nitrites can be used in the United States only in cured meats. Here, its action is largely that of fixing the red color, though the salts also exert some preservative action. Nitrites are extensively used in Canada for treating fish fillets. The storage quality of the fish is much improved, especially if the product is strictly fresh and has undergone no decomposition.

Inert Gases. Inert gases are often used to supplement other preservation methods. Examples, are the use of nitrogen and carbon dioxide in canned foods, nutmeats, coconut and oily foods, where it is desirable to eliminate oxygen. Gases are more useful in glass containers than in tin because oxygen soon disappears from foods packaged in tin containers. Inert gases help to prevent or control oxidative changes such as rancidity in fats. When oxygen is eliminated by inert gases, ascorbic acid in the canned food is conserved. There is some use made of carbon dioxide cold storage in extending the keeping quality of pears, apples, plums and other fruits. The carbon dioxide content of the storage rooms is maintained at 5 to 10 per cent at temperatures of 31.5 to 35°F.

Stabilizers, Softeners and Antioxidants. Many chemical compounds are now used in foods as improvers. In a sense these aid in food preservation by improving quality, texture, storage life and palatability. Examples are Tenox and ethyl gallate (antioxidant for fats); gums and sodium alig-

nate (stabilizers), and sorbitol compounds (bread improvers). Hydrogenation of oils to produce higher melting fats usually reduces their susceptibility to oxidation and facilitates their use in foods.

Antibiotics have been proposed as useful adjuncts in food canning. Subtilin and others decrease bacterial resistance to heat so that it is possible to obtain a sterilized canned food at relatively light heat treatments. The method has no commercial importance at present because of the questionable legal and public health aspects which are involved.

Physical Aids to Preservation

Various physical means are used in food preservation processes such as canning, freezing, fermentation and dehydration. Thus, vacuumization aids in preservation by removing air (oxygen) which often causes deteriorative changes. Of course, vacuum concentration is useful in reducing bulk and in removing water at low temperatures which result in little or no color or flavor injury in the food. By concentrating liquids such as fruit juices, the soluble solids content increases. This improves keeping quality. Sirups containing over 65 per cent sugar solids will not ferment. However, molds may grow on the surface of fruit products containing over 65 per cent soluble solids. Of course, dehydration is a form of concentrating the solids and thus preventing spoilage. By cooking down apple pulp and juice with added sugar to a high solids content, apple butter is obtained. This keeps perfectly without a heat process.

Pressure has little effect on microorganisms. Under high pressure the bulk of some foods may be greatly reduced and thus rendered less liable to attack by microorganisms and insects.

Fats and oils such as melted lard and tallow are often used by farmers to preserve cooked sausages, loins of pork, venison and other meats. Products can be thus stored for several months. The method has little commercial significance. Paraffin and mineral oil are useful in preventing surface spoilage in pickles, apple butter, and jellies. Cheese is protected from excess moisture loss by a paraffin coating. The recent development of latex and plastic films and metal foils have aided immensely in the packaging of foods to prevent moisture loss and quality deterioration.

Water glass (sodium silicate) forms a sirupy solution which is used to some extent to preserve shell eggs. The silicate closes the pores of the shell. If kept in a cool place the eggs keep perfectly for as long as six months.

Filtration alone, may remove microorganisms from liquids such as vinegar, wine, juices and pharmaceuticals. When handled under aseptic conditions these products can be packaged in a sterile condition. Normally, however, filtration alone is not relied upon to remove all microorganisms. A final heat treatment is required. In beer manufacture, filtration is used

to remove the yeasts from the brew. Filtration is an accessory operation common to the manufacture of many liquid foods. It is not a primary means of preservation. Centrifugation is really a form of filtration and is used to separate liquids of different densities or to remove solids which are suspended in liquids.

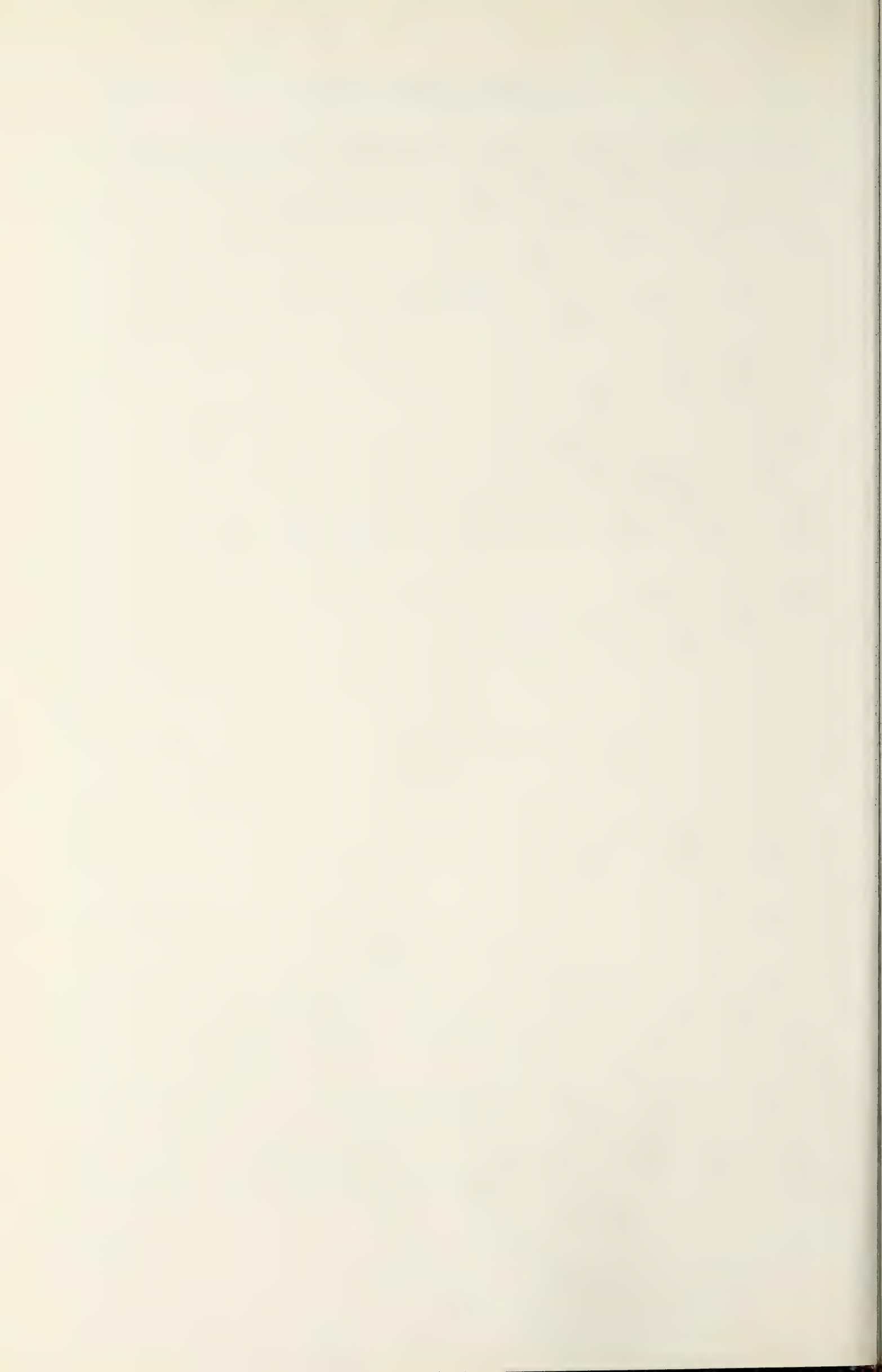
Comminution is used to prepare purees, soups and baby foods. It is not a true means of preservation. The same statement holds for grinding, pulping, and disintegration. All these operations are incidental to preservation.

Radiation sterilization of foods (cold sterilization) is now being actively investigated both under government auspices and at several industrial and university laboratories. While sterilization can be effected in small volume containers the practical applications seem remote at present. In cathode ray supervoltage irradiation, flavor is seriously injured. Furthermore, enzyme inactivation requires several times greater dosages than are required for microbial destruction. Nuclear fission products such as Co^{60} are gamma ray emitters. They have high penetrating powers but the low intensity radiation flux in the available sources requires treatments of many hours. While x-rays are deeply penetrating, most of the energy is lost in the form of heat in the target. Since exposure times are long and the cost is high, the treatment is not economically feasible. Cold sterilization of foods must be presently considered in the early experimental stages.

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12. EFFECT OF CANNING AND DEHYDRATION ON THE NUTRITIVE VALUES OF FOODS

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Canned foods and dehydrated foods contribute greatly to the present American way of life. They allow people to live in locations far distant from the sources of food supply and enjoy the convenience of a wide selection of preserved foods having favorable qualities comparable to fresh raw foods, home cooked. In times of war canned and dehydrated foods have a procurement priority equal to that for ammunition. To do justice to their civilian and military obligations, such foods must be in a reliable state of preservation, be palatable, and carry their share of naturally endowed nutrients to consumers. With regard to the latter it is the purpose of this chapter to provide reliable information on the effects of various canning and dehydrating operations on food nutrients as well as information on the nutritive composition of these two classes of foods.

CANNED FOODS

In view of the large volume of canned foods in the average American diet, it is important that we have a good understanding of the nutritive content of these foods. People generally eat what they like and generally take nutritive value for granted. The canning industry has therefore accepted the responsibility of preserving to the greatest degree possible all of the original nutrients in foods to be canned. Good raw products must be obtained to produce good processed foods. Nutritional qualities cannot be enhanced by processing or by home cooking. From the vast amount of work which has been conducted on nutrient retention during canning and home cooking, it

TABLE 12-1. AVERAGE VITAMIN VALUES FOR SOME COMMERCIALY CANNED FRUITS AND VEGETABLES³

(mg/100 g)							
Item	Product	Ascorbic acid	Carotene	Thiamine hydrochloride	Niacin	Riboflavin	Calcium pantothenate
1	Apricots, unpeeled halves	3.9	1.29	0.018	0.35	0.022	0.094
2	Asparagus, green	15.3	0.31	.064	.82	.094	.19
3	Asparagus, white	15.0	.029	.050	.71	.057	.12
4	Beans, baked, New England style	2.9	.02	.021	.24	.054	.08
5	Beans, baked, with tomato sauce	2.7	.05	.053	.91	.024	.10
6	Beans, green cut	3.3	.18	.029	.32	.035	.062
7	Beans, Lima, green	7.2	.077	.032	.54	.040	.11
8	Beets	3.0	.007	.008	.14	.024	.079
9	Blackberries	6.2	.11	.013	.21	.019	.078
10	Blueberries	13.3	.024	.014	.19	.014	.068
11	Carrots	2.0	7.34	.021	.35	.021	.13
12	Cherries	5.9	0.52	.027	.19	.016	.12
13	Corn, white, cream style	5.5	.012	.027	1.08	.049	.21
14	Corn, yellow, cream style	5.6	.08	.030	0.94	.052	.22
15	Corn, white, whole kernel	4.7	.017	.021	.93	.044	.20
16	Corn, yellow, whole kernel	4.5	.086	.026	.83	.045	.21
17	Grapefruit juice	32.1	.007	.028	.17	.017	.13
18	Grapefruit segments	24.8	.007	.029	.21	.020	.13
19	Kraut	17.6	.031	.034	.11	.041	.093
20	Mushrooms	1.7	.006	.016	1.6	.19	.94
21	Orange juice	34.3	.097	.073	0.24	.020	.12
22	Peaches, halves, clingstone	3.8	.26	.007	.60	.021	.043
23	Peaches, halves, free-stone	2.5	.20	.008	.55	.020	.056
24	Pears, halves	1.5	.006	.009	.14	.018	.023
25	Peas, Alaska	9.7	.29	.092	.87	.054	.15
26	Peas, sweet, wrinkled	9.2	.26	.112	1.00	.057	.15
27	Peppers, sweet red	119.0	1.99	.039	.70	.081	.10
28	Pimentos	113.0	1.38	.025	.38	.065	.18
29	Pineapple piece	8.0	0.03	.052	.18	.018	.10
30	Pineapple sliced	5.1	.03	.070	.17	.021	.10
31	Potatoes, sweet	16.2	5.94	.053	.49	.043	.43
32	Prunes, Italian	1.6	0.72	.023	.36	.020	.65
33	Spinach	13.1	3.29	.019	.32	.095	.053
34	Tomatoes	17.0	0.58	.052	.69	.027	.23
35	Tomato juice	14.2	.51	.053	.78	.028	.26
36	Turnip greens	19.5	2.64	.015	.58	.090	.068

can be concluded that changes in the nutritive content of most canned foods are of about the same extent as those which take place in the preparation and cooking of raw foods in the home.

In 1942 the National Canners Association-Can Manufacturing Institute instituted a large-scale study on the nutrient composition of commercially canned foods². Grants were made to various universities for assaying 43 nonformulated products canned in the United States. The average vitamin content of these canned food products are shown in Tables 12-1, 12-2 and 12-3.

With regard to the significance of the protein, carbohydrate, fat and mineral contents of various canned foods, Kramer¹⁶ developed a classification system which provided a means of readily determining the proximate and mineral contributions of specific canned foods to the diet. The proxi-

TABLE 12-2. AVERAGE VITAMIN VALUES FOR SOME COMMERCIALY CANNED SEA FOODS²⁹
(mg/100 g)

Item	Product	Vitamin A	Thiamine hydrochloride	Riboflavin	Niacin	Calcium pantothenate
1	Mackerel	0.029	0.034	0.20	7.65	0.29
2	Salmon, red	.087	.021	.16	7.81	.57
3	Salmon, pink	.019	—	—	—	—
4	Sardines in oil	.069	.024	.14	4.71	.38
5	Sardines in tomato sauce	—	.010	.22	4.78	.47
6	Shrimp, dry pack	.017	.009	.032	2.23	.29
7	Shrimp, wet pack	.018	.008	.031	1.54	.21
8	Tuna	.008	.037	.14	10.2	.17

TABLE 12-3. AVERAGE PYRIDOXINE, BIOTIN AND FOLIC ACID CONTENT OF SOME COMMERCIALY CANNED FOODS¹²
(μg/100 g)

Product	Pyridoxine	Biotin	Folic acid	
			<i>S. Lactis</i> factor	<i>L. Casei</i> factor
Asparagus, green.....	30	1.7	5.8	9.0
Beans, green.....	32	1.3	2.9	7.7
Carrots.....	22	1.5	1.3	4.1
Corn, yellow.....	68	2.2	1.7	5.6
Grapefruit juice.....	14	0.3	0.5	1.2
Peaches.....	16	.2	.5	1.5
Peas.....	46	2.1	1.7	4.4
Salmon.....	130	9.9	2.6	6.9
Spinach.....	60	2.3	7.4	20.7
Tomatoes.....	71	1.8	2.7	5.4

mate protein, fat and carbohydrate content of some commercially canned foods are shown in Table 12-4 and the proximate mineral content of some commercially canned foods in Table 12-5.

Effect of Canning Operation on Vitamins

In understanding the effects of various canning operations on the retention of vitamins in various food products, it is highly desirable to have a knowledge of the chemical and physical properties of the specific vitamins. No food can be preserved without some sacrifice in vitamin content. Table 12-6 shows some factors which influence the stability of the better known vitamins in foods.

Canning operations vary considerably from plant to plant. Most commercial vegetable canning involves the following steps: (1) preparatory operations such as cleaning, washing, cutting, etc.; (2) blanching or scalding; (3) filling containers; (4) brining; (5) exhausting air from products before closure; (6) closing; (7) sterilizing, usually in the range of 235 to 250°F, and cooling.

Fruits and juices follow somewhat the same procedures except that sterilizing temperatures are generally lower and in the case of juices, continuous tubular heat exchangers may be used for sterilizing the product.

Fruits

Fruits are considered to be valuable sources of ascorbic acid but low in carotene and vitamin B factors. Exceptions to this are carotene in apricots and peaches and thiamine in oranges and pineapple.

Four surveys reported by Guerrant *et al.*⁹, for red sour pitted cherry canning operations, showed a 96 per cent retention of ascorbic acid on a dry-weight basis together with a complete retention of carotene. Lamb¹⁸ reported ascorbic acid retentions in canned apricots of 76 to 97 per cent (dry-weight basis) with 85 per cent average retention for four stages of maturity in two varieties, and carotene retentions on the same product from 78 to 98 per cent with an average of 89 per cent.

Due to the high ascorbic acid oxidase activity of apples it has been observed that it is very difficult to retain ascorbic acid during the canning of apples, apple sauces, or apple juice. Kohman *et al.*¹⁴ reported that soaking apples in a 2 per cent salt solution preserved the vitamin C content during the canning of apple sauce.

Lamb¹⁸ indicated that peeled clingstone peach halves exposed to air for 30, 60 and 120 minutes resulted in losses of ascorbic acid of 29, 34 and 45 per cent, respectively. Peach slices exposed to air for similar lengths of time lost 42, 52 and 58 per cent of their ascorbic acid, respectively.

In 1946, Lamb reported the ascorbic acid, thiamine, niacin and carotene

TABLE 12-4. CLASSIFICATION OF COMMERCIALY CANNED FOODS ACCORDING TO CONTENTS OF PROXIMATE FOOD COMPONENTS¹⁶

Protein (approx.) %	Products
27	Shrimp, dry pack; tuna fish
21	Salmon; sardines in oil; mackerel
18	Sardines in tomato sauce
15	Shrimp, regular pack
6	Beans, baked
4	Beans, Lima; peas
3	Mushrooms
2.5	Corn, vacuum pack; corn, cream style; spinach
2	Corn, whole kernel; asparagus; sweet potatoes; turnip greens
1	Beans, green; tomatoes; tomato juice; pimentos; peppers; orange juice; kraut; cherries; beets
0.7	Blackberries; carrots; apricots; blueberries; grapefruit; grapefruit juice; peaches
0.5 or less	Prunes; pineapple piece; pineapple segments

Fat (approx.) %	Products
20	Sardines; tuna fish
12	Mackerel
7	Salmon
2	Beans, baked; shrimp, dry pack
0.7	Shrimp, regular pack; corn, cream style; corn, yellow, whole kernel
0.5	Corn, white, whole kernel; peas, sweet; peppers; pimentos; spinach
0.3 or less	Apricots; asparagus; beans, green; beans, Lima; blackberries; blueberries; carrots; cherries; grapefruit juice; grapefruit segments; kraut; mushrooms; orange juice; peaches; peas, Alaska; pineapple; pineapple juice; prunes; tomatoes; tomato juice; turnip greens; beets; pears; sweet potatoes

Carbohydrates (approx.) %	Products
25	Sweet potatoes; pineapple slices; peaches, freestone
22	Apricots; corn, yellow, cream style; peaches, cling; prunes; blackberries
19	Beans, baked; corn, white, cream style; corn, yellow, whole kernel; grapefruit segments; pears
14	Corn, white, whole kernel; pineapple juice
12	Beans, Lima; blueberries; cherries; grapefruit juice; orange juice; peas, Alaska
9	Beets; peas, sweet; peppers; carrots
4	Asparagus, bleached; beans, green; kraut, pimentos; tomatoes; tomato juice
2	Asparagus, green; mushrooms; sardines in tomato sauce; spinach; turnip greens
1 or less	Mackerel; salmon; sardines in oil; shrimp; tuna fish

TABLE 12-5. CLASSIFICATION OF COMMERCIAL CANNED FOODS ACCORDING TO CONTENT OF ESSENTIAL MINERALS¹⁶

Calcium (approx.) %	Products
350	Sardines
200	Mackerel; salmon
100	Shrimp, dry pack; spinach; turnip greens
50	Beans, baked; shrimp, regular pack
40	Beans, green; beans, Lima; carrots; kraut; pineapple slices; sweet potatoes
20	Asparagus; beets; blackberries; grapefruit segments; peas; pineapple juice
10	Apricots; blueberries; cherries; grapefruit juice; orange juice; tomato juice; peppers; prunes; tuna fish
6	Corn, whole kernel; corn, yellow, cream style; mushrooms; peaches, freestone; pears; pimentos; tomatoes
4 or less	Corn, white, cream style; peaches, cling
Phosphorus (approx.) %	Products
400	Sardines in oil
300	Salmon; mackerel
225	Shrimp, dry pack; tuna fish
175	Sardines in tomato sauce; shrimp, regular pack
100	Beans, baked
65	Beans, Lima; corn, cream style; corn, vacuum pack; corn, yellow, whole kernel; mushrooms; peas; sweet potatoes
45	Corn, white, whole kernel; asparagus, green
30	Asparagus, bleached; beans, green; beets; carrots; peppers; spinach; tomatoes; turnip greens
20	Apricots; blackberries; grapefruit segments; kraut; orange juice; pimentos; tomato juice
13	Cherries; grapefruit juice; peaches; pineapple juice; prunes
10 or less	Blueberries; pears; pineapple slices
Iron (approx.) %	Products
6.0	Blueberries; kraut; sardines in tomato sauce; turnip greens
3.0	Asparagus, green; beans, baked; beans, Lima; beets; cherries; blackberries; sardines in oil; shrimp; spinach
1.5	Apricots; asparagus, bleached; beans, green; mackerel; peas; peppers; pimentos; pineapple slices; prunes; tomato juice; tuna fish
0.7 or less	Carrots; corn; grapefruit juice; grapefruit segments; mushrooms; orange juice; peaches; pears; pineapple juice; sweet potatoes; salmon; tomatoes

TABLE 12-6. SOME PROPERTIES WHICH INFLUENCE THE STABILITY OF THE BETTER KNOWN VITAMINS IN FOODS³

Vitamin	Soluble in		Affected by oxygen	Affected by heat*	Affected by light
	Water	Fats			
Vitamin A (Carotene and vitamin A)	No	Yes	Yes	No	Possibly
Thiamine (Vitamin B ₁)	Yes	No	No	Yes	No
Riboflavin (Vitamin B ₂ or G)	Yes	No	No	No	Yes
Niacin (P-p-factor)	Yes	No	No	No	No
Ascorbic acid (Vitamin C)	Yes	No	Yes	No*	Possibly
Vitamin D	No	Yes	Yes	No	No

* Assuming absence of oxygen or oxidizing substances.

TABLE 12-7. VITAMIN RETENTION IN PEACHES AS AFFECTED BY CANNING¹⁸

	Clingstone peaches		Elberta peaches	
	No. surveys	% retention	No. surveys	% retention
Ascorbic acid	14		3	
Range		63-90		59-70
Average		71		65
Thiamine	6		3	
Range		60-79		71-93
Average		69		85
Niacin	5		3	
Range		87-92		82-86
Average		89		84
Carotene	4		3	
Range		59-88		88-118
Average		77		102

retentions in canned clingstone and Elberta peaches as shown in Table 12-7.

Studies on lye peeling of clingstone peaches included in the above survey indicated that as peeling time was increased for a given strength of lye, the losses of ascorbic acid increased. Surveys on freestone peaches peeled by steam, indicated an unexpected loss of ascorbic acid. Retentions on the dry basis ranged from 72 to 86 per cent after steam peeling with an average retention of 77 per cent.

Fruit and Vegetable Juices

Citrus Juices. Citrus juices provide one of the best sources of ascorbic acid in the daily diet. Fortunately over-all retentions are high as indicated

by a number of excellent surveys on citrus cannery operations. In these investigations samples were taken at the extractors, after screening, at the holding tanks, from the filler bowl and after processing and cooling. In Florida, Moore *et al.*²³ reported retentions in the canning of grapefruit juice of 88.7 to 101.1 per cent with an over-all average of 97 per cent. Wagner *et al.*³⁷ in a survey of twelve canneries, in the Rio Grande Valley, reported retentions from 92.2 to 99.6 per cent with an average of 96.7 per cent.

Similar high retentions of ascorbic acid have been reported for orange juice with an average retention of 98.3 per cent in five California canneries¹⁹ and 99.0 per cent in a Florida cannery²⁴. Like grapefruit juice, orange juice has an extraordinary stabilizing influence on ascorbic acid and aeration and length of holding of the fresh juice have little effect on the ascorbic acid content¹⁹. Slightly lower retentions, however, may result from traces of copper, derived from copper-bearing equipment, which in the presence of air catalyzes ascorbic acid oxidation.

Biotin, folic acid, pyridoxine and inositol determined on samples of fresh and canned grapefruit and orange juice exhibited favorable stability during the canning operations¹⁷.

Tomato Juice. Tomato juice is similar to citrus juices in its contribution of ascorbic acid to the diet. Unfortunately tomato juice does not possess as favorable an environment for the stability of ascorbic acid during preparation and canning as do citrus juices. The instability of ascorbic acid in tomato juice during manufacture has been pointed out by many investigators such as Kohman and Eddy¹⁵ and Sanborn³² particularly if the aerated juice is held while hot in slow and inefficient tomato juice canning operations. Table 12-8 shows over-all retentions of the principal vitamins in tomato juice²¹. It is apparent that extreme variations in retention of ascorbic acid exist in tomato juice. The reasons for these variations have been extensively investigated^{3, 5, 20} and as a result the causes for poor retentions

TABLE 12-8. PER CENT RETENTION OF ASCORBIC ACID, RIBOFLAVIN, NIACIN AND CAROTENE IN THE CANNING OF TOMATO JUICE²¹

	No. of observations	Range*		
		Max.	Min.	Mean
Ascorbic acid.....	90	90	35	67
Thiamine.....	18	100	73	89
Riboflavin.....	17	100	86	97
Niacin.....	17	100	83	98
Carotene.....	7	74	60	67

* When 30 or more observations were made the maximum and minimum retentions represent the range within which 90% of the observations fell.

TABLE 12-9. RETENTION OF ASCORBIC ACID DURING THE CANNING OF TOMATO JUICE²¹

Sample	Ascorbic acid (mg/100 ml)	% retention
<i>Cannery A—High retention</i>		
Raw, juiced.	26.5	—
Steamed and crushed.	30.0	100
From finisher.	27.8	93
From filler.	28.4	95
Closed and cooled.	28.2	94
<i>Cannery C—Low retention</i>		
Raw, steamed.	27.5	100
Chopped, heated to 195°F.	19.7	72
From finisher.	12.4	45
From filler.	8.3	30
Processed.	8.8	32

are well understood. The average retention of carotene of 67 per cent as reported in this table has been questioned by several investigators since significant destruction of carotene during the actual canning operations seems unlikely. Later investigations on a carotene balance basis showed that the losses of carotene were mainly due to the mechanical separation of skins, cores and seeds. The total destruction of carotene during the canning operations were 4 to 7 per cent. The over-all retention of carotene was approximately 84 per cent.

Plant procedures in the manufacture of tomato juice have a great effect on the retention of ascorbic acid as may be seen in Table 12-9. The important features in Cannery A leading to high ascorbic acid retentions are (1) steaming the tomatoes; (2) extraction of juice at a low temperature and (3) deaeration before heating the juice. In Cannery C the steamed tomatoes were chopped and heated to 195°F by copper heating coils, the pulp then held in a series of storage tanks until it was screened, held again in storage tanks, then salted, filled into cans and processed in a retort. Thus a combination of copper contamination, aeration, and holding of the juice while hot resulted in a considerable decrease in the ascorbic acid content. Similar results have been reported by Clifcorn³ and Peterson and Clifcorn⁵.

Vegetables

Handling of the Raw Product. It is possible in commercial vegetable cannery operations to handle the raw product from the field to the can in the same day and in most instances the canning of vegetables is completed a few hours after harvesting. Thus losses of nutrients during the storage period from harvesting to the start of the first cannery operations for the day are generally negligible. Ascorbic acid and riboflavin are the most vul-

nerable to loss during this initial operation. Gleim *et al.*⁸ have reported losses of 5 to 22 per cent of riboflavin in spinach and asparagus stored in crates in the light for 24 hours. Lamb¹⁸ has reported that asparagus held at room temperature 20.6 to 23.3°C (69 to 74°F) lost 50 per cent of its ascorbic acid in 24 hours with 75 per cent lost in 70 hours. Refrigerator storage at 4.4°C (40°F) showed a loss of 50 per cent of the original ascorbic acid content after 70 hours. Under the latter conditions green beans and spinach lost 50 and 22 per cent of their ascorbic acid, respectively.

Effect of Blanching. Hot water blanching is almost universally employed in the preparation of vegetables for canning. The water-soluble vitamins, ascorbic acid, thiamine, riboflavin and niacin are the vitamins of major concern because of the extraction losses that occur during blanching. Steam blanching, on the other hand, does not cause similar losses although some oxidative destruction of ascorbic acid is believed to take place at the beginning of the blanching period.

As a result of extensive surveys of pea canning operations, Wagner *et al.*³⁹ reported a range of 63 to 85 per cent for ascorbic acid retention during blanching of peas with an average of 71 per cent. The effect of sieve sizes of peas and blanching conditions were also reported by Wagner *et al.*³⁸ as shown in Table 12-10.

In general it was observed that the increase in blanching time affected the ascorbic acid content of peas more adversely than did the increase in blanching temperature.

In a survey on the effect of blanching operations upon the ascorbic acid

TABLE 12-10. SIEVE SIZE AND BLANCHING CONDITIONS AS AFFECTING THE RETENTION OF VITAMINS IN PEAS³⁸

Blanch	Sieve size	Ascorbic acid, mg/100 g dry wt.	Thiamine, mg/100 g dry wt.	Niacin mg/100 g dry wt.
Raw Product	1, 2, 3	136	1.94	10.80
	4	103	1.85	10.80
	5, 6	87	1.73	11.45
		% retained	% retained	% retained
2.5 min @ 76.7–82.2°C (170–180°F)	1, 2, 3	86	93	84
	4	86	85	85
	5, 6	100	95	98
2.5 min @ 93.3°C (200°F)	1, 2, 3	91	89	78
	4	103	99	87
	5, 6	100	98	85
8 min @ 76.7–82.2°C (170–180°F)	1, 2, 3	65	66	67
	4	68	80	63
	5, 6	76	70	64
8 min @ 93.3°C (200°F)	1, 2, 3	64	72	72
	4	73	79	72
	5, 6	76	79	64

TABLE 12-11. RETENTIONS OF ASCORBIC ACID, THIAMINE, RIBOFLAVIN AND NIACIN
AFTER BLANCHING³
(Calculated on the Dry Solids)

Cannery	Type of blancher	Time (min.)	Temp. (°F)	% retention			
				Ascorbic acid	Thiamine	Ribo-flavin	Niacin
1 (1)	Steam	2¾	205	97	—	102	96
1 (2)	Draper	2¾	188	72	—	95	80
2A	Steam	2	205	96	106	96	95
2B	Draper	4½	166–185	78	100	98	99
3	Draper	3½	186–204	64	99	91	90
4 (1)	Drum washer	2¼	140	102	107	104	109
(2)	Rotary	2½	206	55	77	82	71
5 (1)	Rotary	1	160	78	100		
(2)	Immersion	12	160	67	86		
(3)	Immersion	45	160	6	55		
6	Draper	5	170–192	77	91	88	82
7	Rotary	3 and 4½	175–200	72	91	85	74
8 (1)	Steam	55 sec.	210	91	102		98
(2)	Water wash	¼	Cold				
9 (1)	Drum washer	¼	120–130	100			
(2)	Rotary	52 sec.	210	42	54	67	59
(3)	Immersion	18 sec.	185				
10	Draper	6 and 3	185–190	55	81	80	80
11 (1)	Draper	3¼	185–186	74	94	94	97
(2)	Immersion } spray }	5	160–163	5	75	84	81
12	Draper	3½	170–188	78	78	92	82
13 (1)	Sprays	1½	160	28	68	77	69
(2)	Draper	12	160				
14	Drag chain	3	173	65	81	84	80
15	Draper	3	180	68	80		

content of green beans, Wagner *et al.*³⁹ reported retentions of 44 to 83 per cent with an average of 64 per cent. On the Pacific Coast, Lamb¹⁸ reported retentions of ascorbic acid during blanching of green beans of 48 to 96 per cent with an average of 74 per cent. The results of surveys of fifteen canning plants regarding the effect of blanching on the vitamin content of spinach reported by Lamb^{3, 18} are shown in Table 12-11.

The effects of water and steam blanching of a number of products, kale, beets, potatoes, cabbage and carrots were investigated by Von Loesecke³⁵ with regard to their ascorbic acid retention. The results are shown in Table 12-12.

In studies on the effects of blanching on other vegetables, Wagner³⁹ reported that cut green asparagus retained 89 per cent of its original ascorbic

TABLE 12-12. EFFECT OF TYPE OF BLANCH ON ASCORBIC ACID RETENTION³⁵

Product	% retention	
	Water blanch	Steam blanch
Kale	56	80
Beets	63	85
Potatoes	62	77
Cabbage	48	82
Carrots	55	72

TABLE 12-13. THE EFFECT OF BLANCHING ON THIAMINE CONTENT OF VEGETABLES⁴

Item	Grade	Blanching schedule	Blanching loss (%)
Peas (sweet)	Ungraded	8 min., 205°F	24
Peas (Alaska)	#1 Fancy	6 min., 170–190°F	36.4
Peas (Alaska)	#1 Standard	6 min., 170–190°F	15.9
Peas (Alaska)	#2 Fancy	6 min., 170–190°F	21.4
Peas (Alaska)	#2 Standard	6 min., 170–190°F	16.1
Peas (Alaska)	#3 Fancy	6 min., 170–190°F	16.4
Peas (Alaska)	#3 Standard	6 min., 170–190°F	11.1
Peas (Alaska)	#4	7 min., 170–190°F	None
Peas (Alaska)	#5	7 min., 170–190°F	None
Green beans (whole)	#3	6 min., 170–180°F	6.1
Green beans (cut)	#4	6 min., 180°F	16.9
Lima beans	Extra standard	12 min., 208°F	36
Lima beans	Standard	15 min., 208°F	31.9
Asparagus (cut)		1½ min., 170°F	None
Asparagus (whole spear)		1½ min., 170°F	None

acid after either a 6-minute blanch at 190°F or a 4-minute blanch at 150°F. He also reported that ungraded, small and medium lima beans showed 72 and 62 per cent retention, respectively, after blanching 10 minutes at (87.8°C) 190°F.

The effects of blanching on the thiamine content of various vegetables were reported by Clifcorn and Heberlein⁴ and are summarized in Table 12-13.

Effect of Sterilization. The effect of sterilization of canned foods on the nutrient content is primarily concerned with thiamine. Clifcorn and Heberlein⁴ studied the effects of commercial sterilization processes on the thiamine content of vegetables as shown in Table 12-14.

Losses of ascorbic acid taking place during the thermal processing of fruits and vegetables are usually directly proportional to the amount of oxygen entrapped in the can. In surveys of canning operations on peas, asparagus, green beans, Lima beans and whole kernel corn, Wagner *et al.*³⁹

TABLE 12-14. STABILITY OF THIAMINE DURING THERMAL PROCESSING OF SEVERAL VEGETABLES⁴

Product	Process		Can size	% retention during sterilization process
	(min)	(°F)		
Asparagus				
Whole spears.....	14	248	300	66
Center cut.....	14	248	300	63
Fancy cut.....	14	248	300	64
Corn, whole kernel				
White.....	30	250	2	31
Yellow.....	30	250	2	47
Green beans				
Whole, no. 3 sieve size.....	20	240	2	79
Cut, no. 4 sieve size.....	20	240	2	73
Lima beans.....				
Standard.....	30	240	2	71
Extra standard.....	30	240	2	58
Peas, sweet.....				
Unsieved, fancy.....	35	240	2	67
Unsieved, fancy.....	45	245	2	60
Unsieved, standard.....	35	240	2	67
Unsieved, standard.....	45	245	2	67
Peas, Alaska				
Sieve 1, fancy.....	35	240	2	64
Sieve 1, extra standard.....	35	240	2	63
Sieve 2, fancy.....	35	240	2	61
Sieve 2, extra standard.....	35	240	2	64
Sieve 3, fancy.....	35	240	2	59
Sieve 3, standard.....	35	240	2	67
Sieve 4.....	35	240	2	64
Sieve 5.....	35	240	2	69
Tomatoes.....	35	212	2	89
Tomato juice.....	20	212	2	74

reported that the most serious loss of ascorbic acid occurred with green beans, i.e., 20 and 26 per cent loss in two surveys specifically due to the sterilization operation. The other products exhibited little or no loss of ascorbic acid, thus warranting the general conclusion of the authors that ascorbic acid, riboflavin and niacin are not seriously affected by the sterilization operation.

The Effect of Storage on the Vitamin Content of Canned Foods

Temperature and length of time of storage are important variables affecting storage losses of vitamins. Extensive surveys have been made by the NCA-CMI Nutrition Program both on establishing warehouse temperatures

TABLE 12-15. VITAMIN RETENTION IN PEAS, ORANGE JUICE AND TOMATOES DURING Storage IN COMMERCIAL WAREHOUSES^{10, 27, 33, 21}

Locality	Storage temp.		% retention						
			Peas			Orange juice		Tomatoes	
	Ave. (°F)	Range (°F)	Ascorbic acid	Thiamine	Carotene	Ascorbic Acid	Thiamine	Ascorbic acid	Thiamine
12 Months Storage									
New Orleans, La	77	50-98	92	83	97	73	96	83	83
Tampa, Fla	77	54-91	96	85	97	81	95	92	79
Tempa, Ariz	72	50-92	92	89	100	81	99	100	89
Yuba City, Calif	70	54-104	94	92?	100?	92	96	102	86
Oakland, Calif	66	51-87	94	85?	97?	86	99	105	88
Washington, D. C	63	42-79	96	90	98	91	103	101	90
St. Louis, Mo	61	36-87	98	96?	98	91	95	101	89
Rochelle, Ill	59	28-92	96	89	98	90	99	98	89
New York, N. Y	58	30-78	93	91	97	96	98	106	96
Controlled temp	50	—	93	92	98	97	100	95	94
	65	—	91	87	94	92	98	94	93
	80	—	86	74	91	77	89	82	82
24 Months Storage									
New Orleans, La	77	50-98	90	77	96	59	78	84	67
Tampa, Fla	77	54-91	88	82	96	57	81	86	70
Tempa, Ariz	72	50-92	90	82	96	70	91	86	82
Yuba City, Calif	70	54-104	89	79	93	77	91	104	85
Oakland, Calif	66	51-87	92	87	95	77	97	85	86
Washington, D. C	63	42-79	93	86	96	76	99	101	83
St. Louis, Mo	61	36-87	93	88	95	82	99	93	90
Rochelle, Ill	59	28-92	92	88	98	84	95	102	83
New York, N. Y	58	30-78	94	90	97	85	96	99	90
Controlled temp	50	—	91	90	94	95	101	89	91
	65	—	89	85	91	77	89	82	82
	80	—	81	70	90	50	83	70	70

and on determining the losses that occur on storage under “true” warehouse conditions. Table 12-15 summarizes the NCA-CMI studies^{10, 27, 33, 21} on peas, orange juice and tomatoes.

DRIED AND DEHYDRATED FOODS

During World War II dried and dehydrated foods were in great demand for supplying some of the needs of the Armed Forces and for Lend Lease. Prior to this period most of the dehydrated food produced was of inferior

quality except in the case of dried fruits. Little was known regarding the nutritive value of these foods, particularly with respect to the effect of various preparatory operations and storage on the vitamin content.

Many revolutionary changes have been made in producing dehydrated foods in recent years which have served to improve palatability, storage life and nutrient retention. A considerable number of foods have been successfully dehydrated on a commercial scale. Those foods which have achieved the greatest commercial success are listed together with their vitamin content in Table 12-16, as prepared by the U.S.D.A.^{6, 1}.

Dehydrated Vegetables

Under the stimulus of increased demands and consumer acceptance revolutionary developments have taken place in the dehydration of vegetables.

TABLE 12-16. AVERAGE COMPOSITION OF DRIED AND DEHYDRATED FOODS PER 100-GRAM SAMPLE⁶

Product	Vitamin A (I.U.)	Thiamine (Mg)	Riboflavin (Mg)	Niacin (Mg)	Ascorbic acid (Mg)	Ref.
Apples, dehydrated.....	0	0.07	0.10	1.2	12	1
Apples, dried.....	0	.10	.10	1.0	12	1
Apricots, dried, sulfured.....	7,430	.01	.16	3.3	12	1
Beef, dried or chipped.....	0	.07	.32	3.8	0	1
Beets, Julienne, dehydrated.....	70	.13	.26	1.2	5	2
Cabbage, unsulfited.....	540	.53	.38	2.9	218	1
Carrots, dehydrated.....	114,800	.31	.30	3.0	12	1
Chicken noodle soup.....	82	.15	.09	1.8	1	2
Cranberries, dehydrated.....	730	.16	.06	0.7	32	2
Cranberries, dried.....	300	.19	.18	.9	34	1
Eggs, dried whole.....	3,740	.34	1.06	.2	0	1
Eggs, dried white.....	0	0	2.05	.7	0	1
Eggs, dried yolk.....	5,540	.50	0.66	.1	0	1
Figs, dried.....	80	.16	.12	1.7	0	1
Milk, dried, whole.....	1,400	.30	1.46	0.7	6	1
Milk, dried, skim.....	40	.35	1.96	1.1	7	1
Onions, dehydrated.....	130	.25	0.18	1.4	36	1
Peaches, dried, sulfured.....	3,250	.01	.20	5.4	19	1
Potatoes, dehydrated.....	40	.30	.11	4.5	23	1
Prunes, dried, unsulfured.....	1,890	.10	.16	1.7	3	1
Raisins, dried, unsulfured.....	50	.15	.08	0.5	Trace	1
Soups, dehydrated, navy bean.....	0	.42	.19	2.2	1	1
Soups, dehydrated, pea.....	220	.57	.19	3.1	1	1
Sweet potatoes, dehydrated.....	19,980	.21	.14	1.9	32	1
Tomato flakes.....	3,720	.65	.43	6.5	114	1
Tomato juice cocktail.....	8,160	.45	.30	6.5	80	2

Ref. 1. "Composition of Foods—Raw, Processed, Prepared" in *U.S.D.A. Agriculture Handbook No. 8*, June, 1950.

Ref. 2. Pavcek, P. L., and The Committee on Food Composition. "Nutritive Value of Dehydrated Vegetables and Fruits," *Ind. Eng. Chemistry*, **38**, 853, (1946).

Changes in preparatory and blanching procedures, enzyme inactivation, improved dehydration equipment, and a better knowledge of the effects of packaging and storage have done much to improve the palatability and nutritive value. For certain vegetables sulfiting has helped in prolonging the storage life. Obviously, as with canned foods, these operations affect the nutritive value of the products in varying degrees and it is therefore the purpose of this section to summarize the effects of blanching, sulfiting, dehydrating and storage on the nutritive value of dehydrated vegetables.

Effect of Blanching and Dehydrating. Blanching is generally considered one of the most important preparatory steps before dehydrating. Considerable experience was gained during World War II in determining the proper time and temperature for the destruction of enzymes and in preparing the product for the most efficient rate of dehydration. Blanching, however, affects the retention of certain of the vitamins. Hollingshead¹¹ reported the following losses of ascorbic acid as a result of steam blanching in the preparation of the following dehydrated vegetables: beets, 14.8%; cabbage, 18.3%; carrots, 35.8%; kale, 19.7%; mustard greens, 24.5%; and white potatoes, 22.5%.

Morgan *et al.*²⁶ reported the following losses of niacin, pantothenic acid, thiamine, ascorbic acid, carotene and riboflavin during blanching and dehydrating of commercially produced dehydrated vegetables as shown in Table 12-17.

Considerably greater losses in blanching and dehydrating for cabbage and white potatoes were reported by Mallette *et al.*,²² as shown in Table 12-18.

Sulfite is sometimes added to the blanch to prevent deterioration in color and flavor during storage of the dehydrated product. The addition of sulfite to the blanch is beneficial in preventing losses in ascorbic acid but it greatly increases the destruction of thiamine as previously indicated in Table 12-18 and in the report of Pavcek²⁸ for unsulfited and sulfited cabbage, as shown in Table 12-19.

Effect of Storage. The principal factors affecting the retention of vitamins during storage are temperature and type and method of packaging. During 1943-44 the Research Division of the Continental Can Company, Inc., made extensive studies on the retention of vitamins in dehydrated vegetables during storage³⁰. In this study four types of packages were selected: can—air pack; can—air exhausted from can and contents with carbon dioxide before closure; can—air exhausted from can and contents with nitrogen before closure, and paperboard carton. Three storage temperatures were used: 75°F, 98°F and 130°F. The results from this study indicated that riboflavin was fairly stable under all temperature and packaging conditions. Thiamine was affected principally by storage temperatures above 98°F. Ascorbic acid was affected by both temperature and packaging

TABLE 12-17. LOSSES OF VITAMINS IN COMMERCIALY PRODUCED FRESHLY DEHYDRATED VEGETABLES EXPRESSED AS PER CENT OF THE CONTENT OF THE CORRESPONDING FRESH SAMPLES²⁶

Code no.	Vegetable	Niacin, total	Pantothenic acid, total	Thiamine			Ascorbic acid			Carotene			Riboflavin
				Blanching	Dehy- drating	Total	Blanching	Dehy- drating	Total	Blanching	Dehy- drating	Total	
CV 17	Cabbage	0	0	0	22	22	0	30	30				0
37	Cabbage	0	0	10	20	30	16	0	16				0
27	Potatoes	11	0	23	23	46	12	71	83				0
20	Potatoes	0	0	16	18	34	—	—	0				0
23	Carrots	0	0	18	38	56	—	—	0	15		*	0
31	Carrots	33†	0	8	23	31	—	—	0	3	31	34	10‡
34	Carrots	0	0	0	34	34	25	0	25	7	14	21	0
40	Carrots	0	0	22	11	33	24	24	48	16	24	40	0
43	Carrots	0	30†	37	13	50	—	—	0			0	30†
45	Onions	16†	20†	0	34	34	—	18	18				20†
47	Onions	0	0	—	—	—	—	44	44				0
49	Onions	0	8†	—	—	—	—	—	0				0
54	Onions	30†	—	0	30	30	—	43	43				0

* Different variety used for dehydrated sample.
† In dehydration.
‡ In blanching.

TABLE 12-18. LOSS OF VITAMINS DURING BLANCHING AND DEHYDRATION²²

Product	Riboflavin		Thiamine		Ascorbic acid		Niacin	
	Mg/100 g	% total loss	Mg/100 g	% total loss	Mg/100 g	% total loss	Mg/100 g	% total loss
Cabbage—sulfite blanch								
Fresh.....	0.50	—	0.60	—	—	—	3.09	
Blanched.....	.32	36	.33	45	345	—	2.43	21
Dehydrated.....	.41	18	.05	92	250	—	3.30	None
Cabbage—steam blanched								
Fresh.....	0.61	—	0.74	—	477	—	4.43	—
Blanched.....	.48	21	.63	15	380	20	4.20	5
Dehydrated.....	.45	26	.55	26	266	56	3.86	13
White potatoes (steam blanched)								
Fresh.....					103			
Blanched.....					51	50		
Dehydrated.....					25	76		

TABLE 12-19. SULFITED VS. UNSULFITED DEHYDRATED CABBAGE²⁸

Vitamins	Vitamin content—100 g sample	
	Unsulfited cabbage	Sulfited cabbage
Vitamin A, I.U.....	520	600
Thiamine, mg.....	0.41	0.13
Riboflavin, mg.....	.37	.37
Niacin, mg.....	2.4	2.7
Ascorbic acid, mg.....	189	351

conditions with the most favorable retentions at the lower storage temperature and packaging the product in a can with either carbon dioxide or nitrogen. The retention of carotene was somewhat variable depending principally upon the amount of oxygen included in the container at the time of closure. A brief summary of the results of the studies at 75 and 98°F, for products packaged in cans in an atmosphere of nitrogen, is given in Table 12-20.

Dried and Dehydrated Fruits

Sun Drying or Dehydrating. The nutritive value of dried fruits has been well summarized by Tressler³⁴, Von Loesecke³⁶, and Cruess⁷. Briefly, it may be stated that sun drying is destructive of the carotene of raisins, figs, grapes and other fruits. Dehydration, by artificially produced heat under controlled conditions of temperature, humidity and air flow causes little loss of carotene. Ascorbic acid is easily destroyed by either sun drying

TABLE 12-20. EFFECT OF STORAGE TEMPERATURE ON VITAMIN RETENTION OF DEHYDRATED PRODUCTS PACKAGED IN CANS IN A NITROGEN ATMOSPHERE³⁰

Product	Storage time (months)	Temp. of storage (°F)	Package	Carotene (%)	Thiamine (%)	Ascorbic acid (%)	Ribo-flavin (%)	Niacin (%)
Onions	6	75	Can-N ₂			68		
	12	75	Can-N ₂			53		
	1	98	Can-N ₂			69		
	3	98	Can-N ₂			53		
Rutabagas	6	75	Can-N ₂		106	74		
	12	75	Can-N ₂		97	75		
	6	98	Can-N ₂		93	48		
	12	98	Can-N ₂		107	34		
Sweet potatoes	6	75	Can-N ₂	79	106	83	—	
	12	75	Can-N ₂	94	138	87	103	
	6	98	Can-N ₂	74	95	73	—	
	12	98	Can-N ₂	102	118	70	109	
Tomato juice cocktail	6	75	Can-N ₂	32	72	87		
	12	75	Can-N ₂	40	72	98		
	6	98	Can-N ₂	51	64	58		
	12	98	Can-N ₂	57	68	85		
Tomato flakes	6	75	Can-N ₂	26	109	91		
	12	75	Can-N ₂	71	94	49		
	6	98	Can-N ₂	37	98	78		
	12	98	Can-N ₂	37	97	—		
Carrots	6	75	Can-N ₂	92	82		115	
	12	75	Can-N ₂	93	65		96	
	6	98	Can-N ₂	92	47		107	
	12	98	Can-N ₂	57	67		105	
Beets	6	75	Can-N ₂		129		93	
	12	75	Can-N ₂		100		109	
	6	98	Can-N ₂		77		102	
	12	98	Can-N ₂		80		100	
White potatoes	6	75	Can-N ₂		54	91	119	
	12	75	Can-N ₂		58	70	—	
	6	98	Can-N ₂		31	82	100	
	12	98	Can-N ₂		35	100	—	
Cabbage	6	75	Can-N ₂		52	93		
	12	75	Can-N ₂		52	54		
	6	98	Can-N ₂		49	34		
	12	98	Can-N ₂		51	33		

or dehydration although most of the fruits retain their ascorbic acid if treated with sulfur dioxide before drying. However, sulfured fruits lose most of their thiamine, although it should be pointed out that fruits generally are a poor source of this vitamin. Riboflavin appears to be little affected by sun drying or dehydration. Table 12-16 lists the average nutrient composition of the fruits of major interest.

Losses of nutrients during storage are somewhat dependent upon the treatment during drying or dehydration and on the storage temperature. Morgan *et al.*²⁵ reported that in sulfur dioxide treated apricots, ascorbic acid is lost rapidly after the sulfur dioxide content has decreased to less than 400 to 500 ppm. Loss of sulfur dioxide is much more rapid at a high storage temperature than at a relatively low storage temperature. Correspondingly greater losses occur in thiamine, ascorbic acid and carotene as the storage temperatures increase.

Table 12-21 shows the effect of storage on dehydrated apple nuggets and cranberries³⁰.

TABLE 12-21. RETENTION OF VITAMINS DURING STORAGE³⁰

Product	Storage time (months)	Temp. of storage (°F)	Package	Thiamine (%)	Ascorbic acid (%)	Riboflavin (%)
Cranberries	6	75	Can-N ₂		85	
	9	75	Can-N ₂		71	
	6	98	Can-N ₂		60	
	9	98	Can-N ₂		70	
Apple nuggets	6	75	Can-N ₂	71	73	131
	12	75	Can-N ₂	73	60	132
	6	98	Can-N ₂	53	63	119
	9	98	Can-N ₂	—	—	—

TABLE 12-22. RETENTION OF VITAMINS IN EGGS DURING SPRAY DRYING¹³

(Results show range and average of ten samples studied)

Sample	Vitamin A U.S.P. (units/g dry wt.)	Vitamin D A.O.A.C. (units/g)	Thiamine (μg/g dry wt.)	Riboflavin (μg/g dry wt.)	Nicotinic acid (μg/g dry wt.)	Pantothenic acid (μg/g dry wt.)
Emulsified whole egg						
Max.....	60	3.9	7.0	13	3.1	142
Min.....	36	1.0	2.1	8	2.0	53
Average.....	43	2.5	3.9	10	2.5	83
Dehydrated eggs						
Max.....	56	3.3	7.4	14	3.1	137
Min.....	21	1.1	2.7	8	2.1	53
Average.....	39	2.2	3.8	11	2.3	82
Average % retention	91	88	97	110	92	99

Spray Dried Eggs

Klose *et al.*¹³ at the Western Regional Laboratory reported that spray drying of whole eggs has no significant destructive action on the vitamins contained in the egg—namely vitamin A, vitamin D, thiamine, riboflavin, pantothenic acid and nicotinic acid. The results are summarized in Table 12-22. Vitamin A was found to be unstable during 9 months' storage; pantothenic acid and nicotinic acid were quite stable during storage; only a slight loss of riboflavin occurred at the higher storage temperatures; thiamine loss was in direct relationship to temperature: none at 15°F, 46 % at 70°F and 50 % at 98.6°F. The storage data are listed in Table 12-23.

TABLE 12-23. RETENTION OF VITAMINS IN DEHYDRATED EGGS DURING STORAGE^{13, a}

Storage time (months)	Vitamins A, U.S.P. (units/g dry wt.)		Vitamin D A.O.A.C. (units/g dry wt.)	Thiamine (μg/g dry wt.)	Riboflavin (μg/g dry wt.)	Nicotinic acid (μg/g dry wt.)	Panto- thenic acid (μg/g dry wt.)
	Bioassay	Colori- metric					
0	53	52	1.4	2.8	7.9	2.1	65
<i>Storage Temperature 98.6°F</i>							
1	23	38	0.9	2.1	7.9	1.9	66
3	20	22	1.1	2.1	6.9	1.9	66
6	10	13	0.9	1.9	6.8	2.2	64
9	10	11	1.0	1.4	6.6	2.2	66
9 ^b	15	—	—	—	—	—	—
<i>Storage Temperature 70°F</i>							
1	56	48	—	2.9	7.6	2.1	65
3	26	33	—	2.9	7.9	2.0	65
6	29	24	—	2.4	7.4	2.5	67
9	16	11	—	1.5	7.0	2.3	67
9 ^b	19	—	—	—	—	—	—
<i>Storage Temperature 15°F</i>							
1	58	48	1.3	2.9	8.0	2.2	69
3	42	41	1.5	2.8	7.9	2.2	61
6	27	30	1.8	2.8	7.9	2.3	62
9	27	19	1.4	2.6	7.6	2.4	68
9 ^b	26	—	—	—	—	—	—

^a Sample 2 was used in the storage studies.

^b These samples were closed in sealed tin cans; all others were closed in barrels.

TABLE 12-24. VITAMIN RETENTIONS DURING DEHYDRATION OF MEAT³¹

Product	Thiamine		Riboflavin		Niacin		Pantothenic acid	
	Mg/g	% re- tention	Mg/g	% re- tention	Mg/g	% re- tention	Mg/g	% re- tention
Raw pork	6.6		2.3	—	43.7	—	4.5	—
Cooked pork	7.4	71	3.1	107	57.0	88	—	—
Dehydrated pork	13.8	63	7.5	104	124.0	92	10.2	73
Roasted pork	—	68	—	85	—	94		
Raw beef	0.6	—	2.0	—	49.5	—	3.4	—
Cooked beef	0.9	91	3.5	109	77.4	96	4.0	72
Dehydrated beef	1.4	76	6.2	105	134.0	92	6.8	68

TABLE 12-25. RETENTION OF VITAMINS IN DEHYDRATED PORK DURING STORAGE* ³¹

Vitamin	Storage period (days)	Storage temperature in °F					
		−20°	38°	80°	99°	120°	145°
Thiamine	58	14.3	14.1	7.4	1.9	0	0
	130	15.4	14.1	3.8	0.6	—	—
	219	15.9	—	2.0	0.6	—	—
Niacin	219	107.7	—	109.5	107.7	107.6	109.9
Riboflavin	219	6.9	—	6.9	7.0	6.0	5.8
Pantothenic acid	219	11.9	—	12.0	8.4	5.0	4.6

* Potencies of the samples are listed in micrograms per gram.

Dehydrated Meat and Meat Products

Rice and Robinson³¹ have published interesting data on the retention of vitamins during dehydration and storage of meats. Some of their data on the effects of dehydration and storage on the vitamin content of pork and beef are shown in Tables 12-24 and 12-25.

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13. FOOD SPOILAGE AND DETERIORATION

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The spoilage of food by microorganisms has always been of great concern to man. His ability to keep foods from a time of plenty into a time of scarcity has been governed largely by the effectiveness of his control over the causes of spoilage. Since time immemorial there has been a race between man and microbes to see who ate the food first. Primitive man learned that through drying, smoking, salting, fermentation and use of high and low temperatures he could alter the condition of his food to an extent that spoilage was markedly retarded. Although these preservation principles were used for thousands of years man never knew the why of their working. It was not until around the middle of the 19th century that the reason for spoilage was worked out and the principles of spoilage prevention explained.

The spoilage of foods plays a great role in the economics of feeding our population. Thousands of tons of food are moved from the source of production to the user through a maze of devious channels of harvesting, packing, transporting, processing, storing and distributing and at every turn spoilage takes its toll in one form or another. The loss of quality and monetary value and the total loss of product throws an economic burden on the consumer through raising the cost of the food items that he buys, and also on the producer, processor and handler through the loss of effort and productiveness, as well as monetary losses. It is little wonder that so

* The work reported in this Chapter is independent of that done at or for the Quartermaster Food and Container Institute. The views expressed are not to be construed as reflecting the indorsement of the Department of Defense.

much scientific research effort and money go into the solving of the spoilage problem.

The annual spoilage losses in the handling of food in the United States runs into millions of dollars, the total amount being very difficult to determine. Three illustrations are presented to show something of the extent of the problem. According to Buster⁵ the spoilage losses of shell eggs are approximately \$125,000,000 a year. For the most part bacteria and molds are responsible for these losses. In the field of fresh fruits and vegetables one survey of losses in self-service food stores⁵² revealed that the average spoilage loss was \$74.00 of each \$1,000.00 in actual sales. Of 65 commodities studied in this type of store 54 of them showed a loss in excess of 5 per cent. In another survey on fresh fruits and vegetables⁶¹ it was revealed that the average spoilage per van load of produce brought into New York City was 2.1 per cent for 14 kinds of fruit and 3.8 per cent for 31 kinds of vegetables. It was estimated that the total yearly spoilage loss of fresh produce in New York City amounts to about 3,000 van loads. Such losses must be passed on to the consumer in the form of increased cost.

The type of spoilage encountered depends upon the nature of the food, its composition, structure, conditions of storage, and the particular types of microorganisms involved. Bacteria have their nutritional patterns like other plants and grow best on types of food that suit these requirements. That is why specific types of spoilage are associated with certain foods and in turn with certain general types of microorganisms.

Some of the conditions that control the type and extent of spoilage of foods are (a) the moisture content, (b) the pH, (c) the oxygen concentration, (d) the type and availability of nutrients, (e) the presence of growth inhibitors, (f) the temperature of the environment, and (g) the degree of contamination with the spoilage organism. If one is able to shift any of these factors into the range that is unfavorable for the growth of specific types of organisms the spoilage problem can be relieved. For example: as the temperature is lowered below 100°F the rate of growth of microorganisms decreases until at or near the freezing point of the product growth ceases. By choosing particular temperatures to fit the conditions of handling spoilage can be prevented, depending upon the time that the product must be held. Thus, if bacterial growth must be retarded for only a short period a temperature of 45°F may suffice, while longer periods of holding may require 32°F or even freezing the food. Another example is the effect of shifting the pH. If a specific spoilage organism is sensitive to a low pH the addition of enough acid to shift the pH into the unfavorable range may prevent the growth of the organism and solve a spoilage problem.

One of the most effective deterrents of spoilage is the practice of good sanitation and cleanliness. The multiplication of microorganisms is accomplished by division or sporulation. Since millions of organisms or cells

are necessary to cause spoilage in any sizable quantity of food it follows that the greater the numbers of cells present at the start the sooner the population will reach the proportions necessary to cause spoilage. Thus, any means that lowers the initial population or prevents a rapid build up of cells also delays or prevents spoilage. The use of good sanitary practices in the handling of food can often be used to keep microbial populations at such low numbers as to eliminate all danger of spoilage during a particular operation or in subsequent handling. Failure to take advantage of this means of spoilage control often results in low quality merchandise or the total loss of it.

Time is another element that is often overlooked in attempting to solve spoilage problems. In the development of spoilage one factor is dependent upon another. The growth rate of microorganisms is a function of time but it is also dependent upon the particular conditions that prevail. We have seen above that by lowering the temperature the rate of growth can be retarded. Conversely, if it is not possible to control the temperature then rapid handling can be used to accomplish the same end. It is because of the possibilities of rapid movement of product in our modern mechanized era that we are able to move certain produce from far places to the consumer. Only a few years ago this was impossible. Food handling is one place where clock watching pays off.

It is not possible in these pages to cover the entire field of food spoilage and deterioration and, therefore, only important spoilage patterns for four major food industries will be discussed.

Dairy Products

Microorganisms play very important roles in this field. Certain microorganisms are deliberately used to produce textures, odors, flavors and to act as preservation agents, and the success of butter making, cheese making, acid milk production, etc., depends upon the use and control of specific types of organisms. On the other hand, many of the defects of dairy products are caused by microorganisms. Poor texture, off odors and flavors, and alteration of appearance and acceptance result when undesirable microorganisms grow in dairy products. Because of the need for positive control over both the wanted and the unwanted types of organisms the dairy industry has made more use of bacteriology than any of the food industries. Quality control must be an integral part of each manufacturing process in order to be successful in the dairy products field. It is not possible to cover all of the types of spoilage and deterioration in this large field so only a few important examples will be presented.

Fresh Milk and Cream. Milk drawn from healthy cows is sterile or low in viable microorganisms. However, during the handling, processing and distributing of the milk there are many points where contamination

takes place. The extent and type of the contamination is dependent upon the sanitary practices, the equipment design, the temperatures employed, the rapidity of movement, etc. Since so much milk is used as the fresh product an elaborate system of controls, techniques, and tests have been worked out to assist in maintaining the initial quality.

The most frequent type of spoilage is that of souring. This is brought about by bacteria that form lactic acid, generally of the *streptococcus* and *lactobacillus* groups. Not only is there production of acid but the casein is coagulated and the milk eventually changes from a liquid to a semisolid. If the souring is brought about by certain bacilli or organisms causing proteolysis bad odors and off flavors are developed. The type and numbers of bacteria found in fresh milk are related to its quality and the length of time that it will keep. Standard tests for quality of milk⁵⁵ are used to determine the extent of the contamination of the milk. The methylene blue reduction test and the resazurin test have proved useful in judging milk quality as they are much more rapid than the determination of total bacterial counts. If the milk is of good quality and the sanitation used in handling it is good the bacterial count will remain low provided that the product is kept under refrigeration. It is when these necessary precautions are relaxed that spoilage and deterioration take place. Insanitary conditions and warm temperatures quickly give rise to a variety of defects brought about by a variety of organisms.

Sweet curd may be formed by organisms that do not produce enough acid to cause coagulation. This is not a common defect but does occur where aerobic spore formers, members of the *proteus* group and other low-acid producing organisms grow in the milk. This is generally followed by a proteolysis of the protein and the development of bitterness. This type of spoilage is observed in pasteurized milk that has been held too long. Another defect in milk and cream is that of gas formation. Members of the coliform group are sometimes responsible for the formation of gas and the development of off flavors. Another type is that produced by yeasts. Market cream heavily infected with yeasts will fairly explode from pressure within the can when the lid has been hammered in tight or has been wired on. Such infections by lactose fermenting yeasts were extensively studied by Hammer and Cordes¹⁸. The condition generally is found in cream that has been held too long and not properly refrigerated.

While spoilage is likely to occur at higher temperatures there are occasional defects that are favored by lower temperatures. In cases where the low temperature discourages the growth of lactic acid producers ropy milk and cream may be produced. Such organisms as *Alkaligenes viscosus* and members of the coliform group are known to give rise to this troublesome type of spoilage. Hammer and Cordes¹⁷ reported an outbreak of ropy milk due to *Staphylococcus cremoris-viscosi*.

Microorganisms bring about many flavor changes. Organisms that produce lipase and break down the fat may give rise to rancid flavors. Where *pseudomonas* types are concerned there may be musty or potato flavors, similar to the action of the same type of organism on eggs. In held cream the flavor may be cheesy, yeasty, moldy, or even rancid. Such flavors may carry over into butter made from the cream.

Pasteurization is carried out for a two-fold purpose, to kill any pathogens that may be present and to improve the keeping quality through the killing of those organisms likely to bring about abnormal fermentations and spoilage. Unless pasteurization is properly carried out with regard to temperature and holding time the purpose may be defeated. Pasteurization does not accomplish sterility but it should take care of those types of organisms most commonly associated with spoilage. However, the elimination of such organisms as those causing normal souring may bring about conditions favoring types of spoilage that take place only in pasteurized products. As a rule these show up only upon long holding.

Most of the abnormalities cited above are the result of lack of sanitation, cleanliness, improper handling and sanitizing of the equipment and especially incorrect temperatures of holding. There must be an unending attention to details along these lines if the quality of fresh milk and cream is to be maintained.

Butter. We often think of butter as a high-fat, low-moisture product in which there are few spoilage problems. That is because we see only the graded product offered to us in the store. The defects of butter do cause considerable loss. Many of the defects originate in the cream from which the butter is made. As indicated above, there may be several serious spoilage problems with cream. It is difficult in many cases to get proper and prompt cooling of the cream on the farm, as well as difficult to obtain rapid handling and delivery of the product to the creamery. If such details are allowed to slide the bacterial populations in the cream may be enormous by the time it arrives at the creamery. While pasteurization can be depended upon to markedly reduce this population and halt the progress of spoilage it cannot overcome the defects that bacterial growth in the cream may have caused. Thus, certain defects may be carried over into the butter regardless of the attention to proper butter production in the creamery. For example, the growth of mold on the surface of the cream may produce such a network of hyphae that their presence in the resulting butter may cause downgrading or rejection. The presence of mold hyphae is such an accurate index of initial quality that standardized procedures⁵⁵ for their estimation are used in quality control.

Many of the defects in butter have been traced to the water used to wash the butter following the churning. Sorensen⁴⁹ studied over 22,000 churnings of butter and found that the major contamination came from

the creamery water supply and could be eliminated by adequate chlorination. Putrid and cheesy types of spoilage were the most frequent and in many cases the coliform group of bacteria was involved.

Often the defect may arise in the culture used in preparing the cream for butter making. If the culture becomes contaminated the defect may be transferred to the butter. Abnormal components of the butter culture may show up if the culture is carried for some time. Hammer¹⁹ observed a ropy butter culture that seemed to originate by selection within the culture. In this case a *Streptococcus lactis* gave rise to a variety that produced ropiness and he named it *S. lactis*, var. *hollandicus*.

During storage butter may become musty, fishy, putrid or rancid. Undesirable flavors and odors in stored butter have been recorded by Wagenaar⁶⁰. He points out that the bacteria causing this spoilage are acquired during manufacture and that they seem to develop only in butter made from pasteurized cream. The contamination can come from a polluted water supply. Most typical cases are due to the growth of *Pseudomonas putrefaciens*. Good sanitation, prevention of recontamination, thorough working of the butter and proper level and uniform distribution of salt are remedies for this type of spoilage.

Most organisms in the cream which may cause flavor defects in butter can be killed by pasteurization. However, recontamination from equipment and insanitary conditions in the plant, as well as contaminated water supplies may result in far worse conditions than were in the cream before pasteurization.

Moldy butter is mostly a surface phenomenon and may give rise to moldy flavors and a discoloration of the product. As a rule it is found in butter that has been held at too high a temperature. Upon occasion butter will develop various discolorations such as pink, green, yellow or black due to the growth of bacteria, yeasts, and molds.

Certain defects of butter are not due to bacterial action. For example, Hussong *et al.*²⁶ found that fishiness in butter was caused by the presence of copper and generally at a low pH. Evidently the elimination of copper tubing, bronze pumps, etc., has reduced this type of defect markedly. Also, a tallow-like flavor in butter has been traced to an oxidation of certain of the fatty constituents and is not due to bacterial growth. Hussong and Hammer²⁷ found that the reaction could be catalyzed by copper and that it also caused a bleaching of the color of the butter. The oxidation is progressive as all butter eventually becomes tallowy if held long enough.

Cheese. Cottage cheese is sold fresh and must be handled rapidly to maintain quality. Parker *et al.*⁴² found that bacteria were responsible for a slimy or gelatinous curd. The cause may be insanitary practices in handling equipment and from contaminated water supplies. In later stages the

cheese may become fruity in odor, then rancid and putrid. The temperature at which cottage cheese is held for retail sale or in the home is not conducive to long life. Molds and yeasts that tolerate the mild acid reaction often grow in cottage cheese and change the appearance, odor and flavor, especially if the temperatures are not low.

Cured cheese is a product in which a curd has been formed by the use of an enzyme preparation and the whey or liquid phase drained or pressed from the curd. The most prominent type in this country is cheddar. This is a hard variety and the normal ripening is brought about by microorganisms. Microorganisms play a dominant part in the aging of brick, limburger, camembert, roquefort, etc., each being produced under a different set of conditions and depending upon different organisms to bring about characteristic reactions. It is because these exact ends are not always attained that the spoilage and deterioration problems exist.

Pasteurization of the milk from which cheese is made reduces the bacterial load and the specific organisms used as inoculants have a chance to predominate. However, unless sanitation and proper handling are used undesirable organisms may get the upper hand. The formation of acid is one of the secrets of good cheese. Anything that interferes with the acid production tends to lower the quality of the cheese and may lead to spoilage. Low acid production is sometimes found when using lactic cultures due to the growth of bacteriophage, or due to the lack of growth of the typical acid formers. Unless the proper amount of acid is produced the chemical relations typical of good aging do not follow.

One type of spoilage in cheese is gas formation. This causes open holes and cracks in the cheese. Overcast and Albrecht⁴¹ studied gas production by *Leuconostoc citrovorum*. They found that this organism seemed to need association with *S. lactis* to form gas. Kelly³³ found that gas production in limburger cheese was due to coliforms. Hammer²⁰ cites the same organisms as causing gas in cheddar cheese. He also indicates that lactose-fermenting yeasts and certain sporeforming anaerobes are also responsible for gas.

Off flavors in cheese may be caused by a variety of organisms. Bitterness in cheese may be caused by the overdevelopment of acid by a very active starter according to Price⁴⁵. According to Hammer²⁰ several other organisms give rise to bitterness. Rancid flavors are sometimes caused by the activity of lipolytic organisms. As in other types of dairy products the coliform group of bacteria is associated with unclean and other off flavors.

Microorganisms also produce many color defects in cheese. Davis and Mattick⁷ found an aerobe causing rusty spots in cheese and more recently Thome and Lundgren⁵⁶ have reported on rusty cheese. Pink spots have

have been found due to yeast. Molds cause defects in cheese by growing where they have access to air, such as, in cracks in paraffin coatings or cracks in the cheese itself. The contamination may arise through the growth of mold on equipment and in the curing rooms. Various mold inhibitors have been suggested and some of them are in use. Hood *et al.*²³ has reported on a type of rind rot due to mold. It is caused by lack of proper temperature and humidity control in the curing rooms and by the sweating of the cheese caused by temperature fluctuations.

Dry Milk Solids. Milk is dried for reduction in bulk, for extending the possible storage period, and to supply milk in locations where fresh milk is not possible. Spoilage by microorganisms is not a problem in dried milk because the moisture content is below that necessary for growth. However, the quality of dry milk may be influenced by the bacteriology of the liquid milk from which it is made. If acid has developed in the liquid milk it can influence the flavor of the dry milk.

During the processing of the liquid milk and during drying the bacterial count is markedly reduced and reconstituted dry milk will keep fairly well, unless the product has been recontaminated through equipment and utensils.

Most of the deterioration in dry milk is chemical in nature. In dry whole milk hydrolytic cleavage of the fats by lipases will take place unless the heat treatment is sufficient to inactivate the enzymes. Also, a flavor defect of tallowness is brought about by the oxidation of the fatty constituents. This is one of the reasons for reducing the oxygen content and gas packing this product. Coulter *et al.*⁶ have discussed the browning reaction that takes place in dry milk through the combination of the carbohydrates and certain proteins. This reaction gives rise to a caramelized flavor or even a scorched flavor. Lea, Moran and Smith³⁴ point out that as the browning reaction increases there is an increase in insolubilization of the dry milk and that the reaction can be inhibited by lowering the moisture content below 3 per cent. This has been found also to be a means of inhibiting browning in dried eggs and other dehydrated products.

Egg Products

Shell Eggs. The production of shell eggs amounts to about 2½ billion dollars a year. The monetary losses due to physical damage, quality deterioration, and spoilage is estimated at 21 per cent⁵. The largest loss (12 per cent) is due to quality deterioration, in which the physical structure of the interior of the egg slowly declines to the point of total loss. Through loss of moisture and carbon dioxide through the shell, the change in pH, the thinning of the white, and the migration of moisture into the yolk, the appearance of the interior quality changes rapidly and markedly in storage.

This decline is neither microbiological nor enzymatic in nature but is due to a series of chemical and physical changes.

The shell of the egg is porous and contains many pores that permit the exchange of gases during the incubation period to produce a chick. In preserving the egg for food it is necessary to retard the natural processes that were designed for the benefit of the developing embryo. By dipping the egg in oil the pores are closed and the exchange of gases and moisture is retarded. Another way used to retard moisture loss is that of high humidity of the atmosphere of the storage room.

The deterioration of an egg begins as soon as it is laid by the hen. In order to preserve it as a food item it must be refrigerated at once. That is why authorities advocate the frequent gathering of eggs⁴⁴ and rapid cooling. At temperatures below 60°F the rate of deterioration is markedly retarded, but refrigeration must be used even when marketing is carried out in only a few days. The market quality of eggs is determined by a grading procedure⁵⁸ and the market price is based largely on this quality designation. Since there is generally several cents per dozen difference between the grades it is desirable to use every means to retain the quality in the higher grades. This can be done only by employment of rapid movement and low temperatures. Funk⁹, Goresline *et al.*^{11, 14}, and Hayes²¹ have demonstrated the effectiveness of the thermostabilization process in retaining quality in shell eggs during handling, marketing or storage. This process "stabilizes" the white of the egg against the quality deterioration encountered in normal storage.

Cold storage is the most useful means of preventing quality decline in eggs. Storages are maintained at $29^{\circ} \pm 1^{\circ}\text{F}$ and at that temperature eggs can be held for 6 months or longer. In order to retain quality the eggs must be moved into the storage rooms as soon after laying as possible and maintained at uniform temperatures throughout the holding period. Extreme fluctuations in temperature or sweating of the product lead to quality loss.

The surface molding of shell eggs is due to lack of ventilation in the storage room. Local accumulation of moisture in the egg cases provides enough available moisture for the growth of molds. If proper ventilation is provided to equalize the moisture and keep it in the form of water vapor no molding will result even though the relative humidity may be high. For these reasons egg cases are made with spaces between the pieces of lumber and fiberboard cases are provided with ventilation holes.

The spoilage of eggs by microorganisms amounts to about 5 per cent⁵. Even though this may seem small it results in a 125 million dollar loss. Bacterial rotting and internal molding are responsible for the spoilage. Although a considerable portion of these losses is preventable the complexity of the

egg industry makes it difficult to initiate and maintain the necessary corrective measures. Only a portion of the industry is in organized units where the hens are confined, nests kept clean, eggs gathered frequently and cooled promptly, and the eggs moved to market rapidly. The bulk of the eggs are produced as a sideline of other farm enterprises and where it is difficult to maintain practices that lead to top quality produce.

At the time of laying most eggs are sterile. They become contaminated by bacteria that pass through the pores of the shell during the cooling period, while laying in the nest or through handling during the marketing process. Stuart and McNally⁵³ and Lorenz *et al.*³⁹ demonstrated the mode and rapidity of shell penetration by bacteria. Once inside the egg certain bacteria find ideal conditions for growth and enormous populations may be built up unless the eggs are refrigerated. Wolk *et al.*⁶³ have demonstrated the effect of temperature upon the infection of shell eggs. If the contamination is extensive bacterial rots will develop in time even though the eggs are refrigerated.

The major sources of infection are fecal material and soil. When the egg is laid it is moist, has no air cell, and has a temperature of approximately 107°F. Upon cooling the interior liquid shrinks in volume and a vacuum develops which gives rise to the air cell. This entire process causes an inward motion of moisture from the surface and contamination may be drawn into the pores. If the surface of the egg acquires fecal material during the process of laying, or while lying in the nest the conditions are ideal for penetration of the shell. Many eggs are laid on the ground, without the benefit of a nest, and become covered with soil and microorganisms. In such cases contamination of the interior egg liquid is a simple process.

The washing of eggs is another source of interior contamination³². Many dirty or soiled eggs are produced and unless cleaned in some way are of doubtful market value. Unless properly washed in clean water that is warmer than the egg, sanitized, and dried rapidly such eggs will be heavily contaminated. Washed eggs are considered poor storage risks by the industry and in order to avoid future loss they should be immediately marketed as fresh eggs or converted into frozen eggs.

Once the bacteria start to grow inside the egg there is very little that can be done to prevent their growth except through refrigeration. Funk⁹ and Feeney *et al.*¹⁰ have suggested a type of pasteurization to kill the bacteria by heating the egg without injuring the functional quality of the egg. Even at a storage temperature of 29°F certain spoilage bacteria multiply slowly and produce green rots, white rots, red rots, black rots, mixed rots and many other types of inedible eggs. When the temperatures of holding are much higher the condition develops more rapidly. In fact, many eggs become rots during the period between laying and reaching the egg handling

plant engaged in packing eggs for immediate marketing or for storage. Such loss eggs are the result of lack of refrigeration and rapid handling. Fortunately rots or loss eggs can be sorted from the good eggs during the candling or grading process.

Mold spots beneath the shell are a troublesome type of spoilage. Such spots are encountered in storage eggs and show up before the candling light as dark spots just beneath the membrane. They are sometimes found in eggs that have been oiled with oil that has been used extensively without filtration or sterilization. In such cases the dirty oil has acted as the contamination carrier. This can be prevented by the use of clean sterile oil.

One type of egg that is difficult to detect by candling is referred to as green white, hay egg, or musty egg. When the egg is broken open it has a musty odor, an off flavor, and a greenish cast to the white. This type of egg causes a great deal of concern since due to the difficulty in detection it may get through to the consumer. Levine and Anderson³⁶ isolated *Pseudomonas* types of bacteria from musty eggs while Turner⁵⁷ found that certain *Achromobacter* also produced mustiness. More recently Lorenz *et al.*³⁸ have shown the development of the green white type of spoilage. This defect cannot be detected by the normal candling operation but it is possible to detect fluorescent eggs containing *Pseudomonas* bacteria by the use of an ultra-violet candling light. The use of this light has been described by Lorenz³⁷. Considerable research effort is pointed toward development of means to prevent and to detect this sour egg or *Pseudomonas* type of spoilage.

Frozen Eggs. There is no bacterial spoilage problem with frozen eggs if they are kept frozen and properly stored. A physical change in plain frozen yolks takes place during long-term storage in which the texture becomes rubbery and difficult to reconstitute. This has been overcome by the incorporation of approximately 10 per cent sugar or 10 per cent salt in products that can be used by specific industries.

The spoilage problem arises during the period of manufacture before the product is frozen. Frozen eggs are made from the broken out liquid of shell eggs. It is, therefore, essential that a thorough sorting be made, as the eggs are broken, to insure that no rots, blood spots, blood rings, and eggs of off odor and appearance go into the product to be frozen. One musty egg can cause several hundred pounds of product to be off quality or even inedible.

Eggs of doubtful quality are likely to have very high bacterial counts⁴⁰. As indicated above, high bacterial counts become higher, and rapidly, unless the temperature is lowered rapidly and the product handled quickly. If the count of the egg liquid is low it can stand considerable abuse without becoming inedible, but even good eggs will lose quality unless they are frozen promptly. A standard 30-pound can of liquid egg should be frozen solid in about 60 hours, or less, and certainly in no longer than 72 hours.

This calls for temperatures below 0°F, the cans stacked far enough apart to allow circulation of cold air, and the air circulated in the room by fans. When these factors are lacking spoilage moves in.

In slow frozen products a shell of ice forms next to the tin and becomes an insulator against the freezing of the center of the can. The egg freezes slowly toward the center and the "core" is the last to freeze. Because the "core" is insulated by the ice the temperature drops slowly and if the bacterial count is high there is ample opportunity for the bacteria to multiply to enormous populations. When this happens a "sour core" results and the product becomes inedible. The defenses against this type of spoilage are good raw material, proper freezing temperatures and movement of air to insure rapid freezing.

Frozen eggs of high bacterial counts spoil rapidly upon thawing or impart high counts to the products in which they become ingredients. Stewart⁵¹ and Goresline *et al.*¹³ have demonstrated the effectiveness of pasteurization of liquid eggs in reducing the bacterial numbers and Winter *et al.*⁶² found marked improvements in keeping quality.

Dehydrated Eggs. There is very little microbial spoilage problem with dried eggs except where the humidity of storage is high. If the product is allowed to absorb moisture to a content above 10 per cent molding will take place even at 32°F. Under these conditions there is also a marked quality deterioration due to chemical changes that are accelerated by high moisture conditions. Stuart *et al.*⁵⁴ and Hirschmann and Lightbody²² showed that deterioration from bacterial action could take place in dehydrated whole egg even though growing cells were absent. Their work indicated that large bacterial populations in the initial product could bring about deterioration during storage in the dry state and that liquid eggs of poor sanitary history were poor risks when used to produce dehydrated eggs.

The browning reaction has been one of the most serious deteriorations in dried eggs. The carbohydrates combine with certain proteins to form dark insoluble products which impart a very undesirable flavor. Considerable research has been done on this reaction and it has been found that lowering the moisture content to 2 per cent or acidifying the liquid before drying will markedly reduce the rate of deterioration. This work has been reviewed by Lightbody and Fevold³⁵. More recently a method of eliminating the browning reaction in eggs by removal of the sugar by yeast or by enzyme treatment has been worked out.

Fruits and Vegetables

Fresh Products. The growing tissue of fruits and vegetables are resistant to the action of spoilage microorganisms. However, anything that changes the metabolism of the tissues is likely to cause deterioration and

spoilage. Such things as injury to the tissue, approaching maturity, severing of the fruit or vegetable from the plant or removing from the earth, bring about a change in the metabolism and the resistance to the inroads of spoilage organisms is lost. An imbalance in the activity of enzyme systems is also brought about by these changes and enzymatic types of deterioration may take place. The resulting enzymatic changes may also accelerate the activities of the spoilage organisms.

The best protection against fruit and vegetable deterioration is to select those conditions for handling, storage and processing that offer the least encouragement to the growth of microorganisms or those which hold the enzyme activity to a minimum. Some of the means used are care in handling the fresh product to prevent breaking of the protective outer covering and prevent bruising of the soft tissues, refrigeration to minimize the growth of microorganisms and to reduce the enzyme activity, the use of inhibitors for both enzymes and microorganisms, and treatments to kill bacteria and to inactivate enzymes.

One reason for using refrigeration in the handling of fruits and vegetables is to reduce the respiration rate and thereby reduce the amount of heat evolved by the product. All products do not respire at the same rate. This may be illustrated by the following figures taken from U.S.D.A. Circular 278⁴⁶.

Product	Temp. of storage (°F)	Btu evolved per ton per 24 hr
Apples	32	1,500
	40	2,600
	60	7,880
	70	12,380
Lettuce	32	11,320
	40	15,990
	60	45,980
Lemons	32	580
	40	810
	60	2,970
	80	6,200

The heating is brought about by biochemical changes due to the activity of the enzymes. It can be seen that the lower the temperature at which the product is held the less heating. Also, that as the temperature is allowed to rise the release of heat increases. In tight piles of product the temperature may build up and spoilage bacteria grow at a very rapid rate. The bacterial activity also evolves energy and further raises the temperature. The high respiration rate of lettuce indicates why it must be packed in ice to prevent spoilage. Unless lettuce is cooled it heats and the growth of spoilage or-

ganisms produce a sick wilted condition that soon results in total loss. On the other hand the slow respiration rate of lemons shows why they will tolerate higher temperatures than some other types of products.

The heat evolved through respiration increases the refrigeration load and unless the temperature is kept down will bring about conditions for bacterial spoilage and a rapid quality decline. With increase in temperature there is also an increase in the rate of maturity development and the breakdown of the tissues. Spoilage and quality deterioration can be markedly reduced by the use of good ventilation to dissipate the heat and to prevent the development of anaerobic conditions by supplying oxygen to the product. Sanitation is also very helpful as good sanitation prevents contamination during handling. By keeping the bacterial numbers at a minimum through cleanliness there is less chance for the development of populations that will cause trouble.

Not only do enzymes bring about increases in respiration rate but they may also cause spoilage and quality deterioration. One type of enzymatic spoilage causing a marked loss of quality is that of enzymatic browning of the tissues. Certain products brown while others do not because the oxidizing enzyme system causing browning is present in the one type and lacking in the other. The tissues of the apple, apricot, banana, cherry, peach, pear, potato and others contain phenolase and darken upon maturity, injury or exposure of the surface to oxygen. On the other hand citrus fruits, pineapple, melons, tomatoes, carrots and others do not darken because they lack this enzyme system. Joslyn and Ponting³¹ have published an excellent treatise on the chemistry of the enzymatic browning reaction.

Browning or enzymatic darkening of tissue does not take place in intact cells even in those products that are susceptible to browning. It is only upon injury or the breaking down of the cell structure that the reaction takes place. When fruit is bruised, cut for canning or drying, or injured by freezing, the tissues turn dark. Overmaturity brings about a change in the permeability of the cell walls with a resultant activation of the browning reaction. The same is true when the fruit is cut for processing. One control, therefore, is the selection of fruit for shipping, storage or processing at a stage of maturity where the chances for discoloration are at a minimum. While cool storage markedly retards this type of deterioration great care must be taken to provide ventilation to prevent the accumulation of moisture due to respiration, with the increased chances for mold and bacterial growth, and to provide adequate oxygen for the control of the direction of respiration. If the concentration of oxygen becomes low physiological damage to the cells result and darkening will take place. This has been demonstrated by Bennett *et al.*⁴ in the case of black heart in potatoes in storage. If the oxygen becomes depleted in the center of the pile of

potatoes there is an accumulation of respiratory intermediates and dark areas appear on the inside of the potato tuber.

In the canning, freezing and drying industries there is often a great deal of quality and monetary loss due to the enzymatic browning of the cut surfaces of products. The cutting breaks open the cells and upon exposure to oxygen the surface darkens rapidly. It has been found that the removal of oxygen or minimizing the access of oxygen offers marked protection. The submerging of cut pieces in water is one method used. The use of sugar solutions to decrease the oxygen absorption and the use of enzyme inhibitors such as ascorbic acid, sulfurous acids, sulfite dips, etc., are employed in industry.

Of special interest in the freezing of vegetables is the use of heat to inactivate the enzymes. Steam or hot water blanches are used to inactivate the phenolases that would otherwise slowly bring about darkening and off flavors during storage.

Dehydrated Products. The dehydration of food products is used to place them in a condition that is more resistant to spoilage and deterioration. As the moisture is removed the dissolved and total solids are increased and finally a point is reached where the amount of water available to microorganisms is below that required for their growth. This point varies for different products depending upon the dissolved solids content, pH, and presence of growth-retarding agents such as sulfur dioxide.

Molds can grow at much lower available moistures than bacteria and, therefore, spoilage of products in the dehydrated state is generally brought about by molds. The point at which bacteria are likely to cause trouble is during the dehydration process. If the initial bacterial population is high, and the drying process prolonged an enormous population of souring organisms is likely to develop. This gives rise to off flavors and very poor quality in the product. This is particularly true where there is overloading of the drying equipment or inadequate air circulation. Under those conditions the moisture cannot be withdrawn rapidly enough to retard bacterial cell growth, and at the elevated temperature used in drying the rate of multiplication is accelerated. Where souring or molding during dehydration is a problem it can generally be eliminated by better adjustment of the air flow conditions either in the equipment or through the product. Vaughn⁵ has pointed out the conditions which favor souring during the dehydration of onions and potatoes, and indicates the enormous bacterial populations that develop under these conditions. Sulfur dioxide and sulfites are often used in the drying of both fruits and vegetables, partly to retain the color and partly to act as an inhibitor to the growth of microorganisms. Ross⁴⁷ points out that sulfiting of potatoes inhibits browning during processing and that browning is influenced by the moisture level and temperature,

also, that browning is more severe in potatoes of high reducing sugar content. Off flavors are associated with browning in this product.

The storage humidity and the temperature at which dehydrated products are held play important roles in the control of spoilage. A product may be dried to a satisfactory moisture range, and would keep for long periods of time if maintained in that condition, but if stored under conditions of high humidity it may pick up enough moisture to support mold growth. This is aptly illustrated in photographs presented by Barger, Pentzer and Fisher³ in which the mold growth is shown to progress inward slowly from the edge of the carton in products stored at high humidities. These workers point out that low temperatures and low humidity are good protection against molding in dried fruits and advocate 32°F storage at not higher than 50 to 60 per cent relative humidity for long-term storage. Likewise, Stadtman *et al.*⁵⁰ have pointed out the importance of moisture level and SO₂ concentration in the drying and storage of fruit.

Frozen Products. Spoilage and deterioration problems of frozen products are largely those that take place prior to freezing, and those due to inadequate or inefficient processing and handling. The molding of fruits and the development of high bacterial counts in vegetables can take place as the raw material is moved from the field to the processing plant. High temperatures, delays in handling, and lack of ventilation can be very detrimental to quality.

The blanching of vegetables accomplishes two things, both of which prevent quality deterioration. The blanching kills or inactivates many of the bacteria that are on the vegetables and it inactivates the enzymes that cause quality loss, off flavors and change in color. Blanching also kills the plant cells and stops respiration. If the vegetables are frozen without blanching there is a gradual development of "hay flavor."

Good sanitation during preparation, processing and handling is essential for good quality frozen products with low bacterial counts. Hucker²⁵ has shown the result of good sanitary practices in commercial plants. Pederson⁴³ pointed out that under room temperature conditions the bacteria on vegetables are in the rapid growth phase and will continue to grow at the same rate unless subjected to low temperatures. He points out that recontamination by the bacteria from equipment and the plant are more likely to yield high counts in the final product than those coming from the fresh vegetables. Thus, if there is delay in getting the product to the freezer or the freezing is slow there is likely to be serious quality destruction due to bacterial growth.

Meat Products

Fresh Meat. The bacterial spoilage of fresh meat is very rapid under ordinary handling conditions. It is largely a surface phenomenon except

in ground products. In order to decrease the rate of bacterial growth meat is refrigerated below 45°F, and preferably between 32 and 35°F. Even at these temperatures the psychrophilic bacteria multiply. Quick chilling of the meat carries the temperature below the range of rapid mesophilic bacterial growth and prevents the development of high population which often occurs when meat is cooled slowly. Microorganisms of the *Pseudomonas*, *Achromobacter*, *Proteus* and *Micrococcus* types grow on the surface of fresh meat. They produce off odors and give the meat surface a slimy appearance. This has been pointed out by Haines¹⁶ in a study of "slimy" meat.

If the meat is allowed to stand for a few hours at temperatures of 70 to 80°F the bacteria will develop a high population and will continue to slowly multiply even though the meat may be chilled to the proper holding temperature. Ayers¹ has reviewed the effect of initial contamination, the temperature of holding, and the populations necessary for development of off odor in meat products. Ayers *et al.*² showed that on chicken meat the total number of microorganisms reached a value of approximately 1,000,000,000 per sq cm before sliminess and off odor were marked. Also, that whereas chicken meat spoiled in 2 to 3 days at 50°F it could be kept for 16 to 18 days at 32°F.

Good sanitation and care in the processing and handling of meats are necessary to hold down the initial contamination. With good practices in the plant the initial populations will be low and the holding time markedly lengthened. Goresline *et al.*¹² showed that in the dressing and eviscerating of poultry the use of in-plant chlorination was effective in holding down the bacterial contamination. More recently, Drewniak *et al.*⁸ have pointed out the sanitary practices that show promise in controlling bacterial populations in poultry processing. Gunderson, McFadden and Kyle¹⁵ have published an excellent treatise on the Bacteriology of Poultry Processing, in which the effects of temperature, sanitation and other factors on bacterial counts are demonstrated.

Jensen³⁰ found the moisture content of the surface of the meat to markedly influence the bacterial growth. Certain bacteria have a rather critical growth range with respect to surface moisture or relative humidity of the atmosphere. Jensen demonstrated this by increasing the agar content of a culture medium: at the low concentrations the bacterial growth was good but as the agar concentration was increased the "binding" of the water had a marked influence on the bacterial growth. The wetting or sweating of meat and high humidity conditions of holding should be avoided as one means of checking spoilage.

A spoilage condition known as "green struck" is sometimes encountered in dressed poultry. This is found in poultry that has been held too long at room temperature or cooled very slowly. Bacterial growth in the intestines of the bird gives rise to a putrid condition with the evolution of hydrogen

sulfide. During long cooler storage or during freezer storage a green coloration develops in the meat and skin adjacent to certain portions of the intestines. This condition can be prevented by rapid cooling and handling. Visceral taints in the poultry meat are the result of bacterial growth.

In beef certain color defects are caused by bacterial action. Jensen³⁰ indicates that certain pigments and discolorations on meat are caused by bacteria or by the chemical changes that they bring about.

Cured Meats. In seeking ways to prevent the spoilage of fresh meat, and to markedly extend the keeping quality, the use of curing agents has been developed. Most of these agents are bactericidal or bacteriostatic in nature. Salt, nitrates, nitrites, smoke, etc., are employed in producing ham, bacon, certain sausages and corned beef. Although these products keep well, especially under refrigeration, certain types of spoilage occasionally occur. One type is the souring of hams. Jensen³⁰ has presented an excellent review of research on almost $\frac{1}{2}$ million hams. He showed that souring of the interior of the ham and bone marrow was associated with infection during the killing operation, as bacteria could be pumped into the interior during the dying period. The types of bacteria involved in souring were *Achromobacter*, *Clostridium*, *Pseudomonas* and *Bacillus*. Sanitary practices and rapid and uniform distribution of the salt were factors in controlling this spoilage defect.

In the curing of meats the anaerobic or putrefactive spoilage is prevented by the use of nitrates which make oxygen available to the bacteria. Also, there is a marked improvement in the color of the meat through the reduction of the nitrates by bacteria. *Clostridia* will not grow in the presence of nitrates. In the curing of bacon bacterial gums or slime are sometimes found in the curing liquor. Also, the surface of certain sausages and frankfurters become slimy if the surface is not kept dry. Sweating or the drip of water of condensation may bring this about. Very often the physical condition and not the type of microorganism is important in the keeping of meat products. The smoking of hams, bacon and sausages brings about a drying of the surface and the absorption of the bacteriostatic agents of the smoke by the meat. Thus, a more durable surface is presented in that the surface moisture is reduced below the value required by most bacteria. Molds are able to grow at lower moisture contents and under certain conditions cause spoilage of cured meat products.

Certain types of bacteria accelerate fat oxidation or break down the fat. Some bacteria can oxidize meat fats directly but most species bring about an initial hydrolysis of the fat²⁴. The growth of lipase or oxidase forming bacteria bring about rancidity in fats with the formation of free fatty acids and oxidative products. Jensen and Grettie²⁹ have shown that this may take place in the fat of cured meat at a moisture content as low as 0.3 per cent.

Also, that there is a correlation of the original numbers of bacteria on the fat and the tendency to become rancid during storage.

The green discoloration of meats has been indicated by Jensen³⁰ to be the result of the formation of hydrogen sulfide by bacteria with a subsequent reaction of the sulfide with reduced meat pigments to form a purple compound. Upon oxidation the purple compound turns green. Certain purple discolorations of fats are caused by the change in certain bacterial pigments by the action of peroxides in the fat upon becoming rancid²⁸.

It has been pointed out that the economic and material losses due to spoilage and deterioration in the food industry are very large. Many of these losses are preventable if care and control are exercised in the handling, processing and storing of the food products. Some of the types of spoilage and deterioration in certain products have been pointed out and indications given of some of the remedial measures that may be used for their correction. We have seen that low temperatures, rapid handling, and good sanitation are the keynotes to the maintenance of quality through the channels of marketing.

The food industry is a multi-billion dollar enterprise and there is no more profitable field offered to research and education than that of developing means of preventing spoilage and deterioration. If sufficient attention were paid to the perfecting of the techniques necessary for preventing or lessening quality deterioration, and to the teaching of those techniques to those engaged in the handling, processing and storing of foods, savings of millions of dollars a year could be realized. These savings could be passed on to the consumers in the form of better quality merchandise at a lower cost.

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14. CEREALS AND CEREAL PRODUCTS*

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INTRODUCTION

Production of Cereal Grains

The cereals are important members of the grass family, *Gramineae*, which, together with the legumes, *Leguminosae*, comprise the world's foremost sources of food and feeding stuffs^{15, 16, 38}. Most widely grown of the cereals are wheat, corn, oats, rye, rice, barley and sorghum. Buckwheat, though not a member of the grass family, is so similar in composition and usage that it is usually considered among the cereals. These economically important cereals, their botanical names and some recent production figures are shown in Table 14-1.

Cereals as Food

Composition. The structure of cereal grains is similar in that they are all a nut-like fruit containing only one seed. The embryo occupies only a small portion of the seed, the bulk of it being taken up by the floury portion, or endosperm, which makes up the food reservoir. The outer covering, or bran layers, are high in protein, cellulose, hemicellulose and mineral constituents while the endosperm consists largely of starch granules embedded in a matrix of protein. The germ is rich in proteins, lipids, sugar (chiefly sucrose) and in ash constituents.

Nutritive Value. Cereals are the most concentrated and cheapest sources of food energy known. Though their chemical composition varies widely due to varietal, soil and climatic factors, they are characterized by their relatively low protein content and high nitrogen-free extract of which 90 per cent or more is starch. The protein content of cereals is an important

* See also Chapters 10 and 16.

TABLE 14-1. PRODUCTION OF ECONOMICALLY IMPORTANT CEREAL GRAINS^a

Common Name	Botanical name	U.S. acreage Harvested		U.S. production		Percentage of estimated world production ^b
		Av. 1945-49	1952	Av. 1945-49	1952	
		<i>1000 acres</i>	<i>1000 acres</i>	<i>million pounds</i>	<i>million pounds</i>	<i>%</i>
Wheat		71,024	70,585	72,144	77,487	17.6
Common	<i>Triticum vul-</i>					
	<i>gare</i> Vill.					
Club	<i>Triticum com-</i>					
	<i>pactum</i> Host.					
Durum	<i>Triticum durum</i>					
	Des.					
Corn or maize ^c	<i>Zea mays</i>	85,696	81,359	171,184	185,177	59.0
Oats		40,184	38,643	44,049	40,585	30.1
White and						
yellow	<i>Avena sativa</i> L.					
Red	<i>Avena byzan-</i>					
	<i>tina</i> L.					
Barley		10,713	8,264	13,119	10,896	8.3
2-row	<i>Hordeum disti-</i>					
	<i>chon</i> L.					
6-row	<i>Hordeum vul-</i>					
	<i>gare</i> L.					
Rye	<i>Secale cereale</i> L.	1,810	1,385	1,340	955	1.0
Rice	<i>Oryza sativa</i> L.	1,690	1,972	3,548	4,866	1.4
Sorghum, grain.	<i>Andropogon</i>	7,100 ^d	5,089	7,425 ^d	4,666	—
	<i>sorghum</i> Brot.					
Buckwheat	<i>Fagopyrum es-</i>	387 ^d	161	332 ^d	158	—
	<i>culentum</i>					
	Moench.					

^a Compiled from U.S.D.A. Agricultural Statistics, 1953¹.
^b Based on revised U. S. production and estimated world production for 1952.
^c Relates to corn for all purposes, i.e., grain, silage, fodder, hogged off, grazed, etc.
^d Average for 1941-1950.

index of quality for certain types of food products but, as a class, cereal proteins are not so high in biological value as those of certain legumes or animal products. Wheat and corn proteins, for example, are lacking in the essential amino acids, lysine and tryptophan. However, the normal American diet at present includes sufficient animal products to effectively supplement the cereal proteins and cereals are important and valuable sources of amino acids for the building of body proteins.

Cereals are generally low in the nutritionally important element calcium and its concentration along with other ash and vitamin constituents is

TABLE 14-2. ENRICHMENT STANDARDS^a
(In mg/lb unless otherwise specified)

Required	Bread		Flour		Farina ^b		Corn meal and grits		Macaroni	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Thiamine....	1.1	1.8	2.00	2.50	2.0	4.0	2.0	3.0	4.0	5.0
Riboflavin...	0.7	1.6	1.20	1.50	1.2	2.4	1.2	1.8	1.7	2.2
Niacin.....	10.0	15.0	16.00	20.00	16.0	32.0	16.0	24.0	27.0	34.0
Iron.....	8.0	12.5	13.00	16.50	24.0	200.0	13.0	26.0	13.0	16.5
Vitamin D...					3200					
Optional....										
Calcium...	300	800	500	625	2000		500	750	500	625
Vitamin D (USP units)...	150	750	250	1000			250	1000	250	1000

^a From Federal Security Agency, Food and Drug Administration Service and Regulatory Announcements¹³.

^b Proposed new standard—Final FDA order not issued as of 3/1/50. Old standard still in effect.

reduced by the refinements of milling processes. Methods of enrichment have been developed, however, which maintain or even increase the nutritional value of the cereal grains in their processed products.

Enrichment. “Enriched” is the term chosen by government and industry in 1941 to describe the characteristics of foods which have been improved through the addition of nutrients for the purpose of fulfilling the nutritional needs of the mass of population. Enrichment of cereal foods on a large scale began in 1941 with the addition of a finely powdered mixture of thiamine, niacin and iron to wheat flour during the milling process. Riboflavin was included in 1943. Since 1941, Public Hearings have been called by the Food and Drug Administration to consider enrichment of a number of staple foods, and Standards have since been established. Federal enrichment standards for enriched cereal foods are given in Table 14-2. In 1953 the Food and Nutrition Board of the National Research Council reaffirmed a previous statement endorsing the enrichment of flour, bread, corn meal, and white rice. The magnitude of the enrichment program in the United States is emphasized by the fact that, in 1950–53, sufficient ingredients were sold to enrich from 77 to 81 per cent of the total amount of flour sold for family use or for commercially baked bread, rolls and buns for civilian consumption⁶¹. Many countries, including Canada, Sweden, Denmark, England, Chile, Brazil, and others permit, require, or are about to enact laws requiring some type of enrichment of white flour.

Cereals as Farm Crops

In addition to the high food value, the prominence of cereals as food plants is due to their wide adaptability to a variety of growing conditions, high yielding ability, ease of cultivation and excellent storage properties. Cereals have been in cultivation since the beginning of recorded history. Their origin is largely unknown but they are all considered hot climate grains. Most of them have been adapted to regions of moderate temperature. Corn is the only one indigenous to the Americas.

Varieties. New varieties of all grains are being produced steadily by plant breeders throughout the world. The goals are to improve yield per acre while also improving or maintaining quality. The first goal may involve improvements in earliness, straw strength, insect resistance, or adaptability to special environmental factors, such as drought or excessive moisture, heat or cold; but the major search is for resistance to diseases such as rust that can create epidemics of drastic proportions. Quality is frequently of secondary importance in breeding programs, except when strong industries (e.g., milling, malting, baking) have established a demand for a quality product at premium prices.

Despite difficulties, varieties of much improved yield have been produced periodically in most grain-growing countries over the past few decades. The average life of a good variety (from introduction to a marked decrease in popularity) is about 15 years. In most countries, 10 to 30 varieties of each cereal will be grown by farmers; some are increasing, some holding their own, and some decreasing.

Harvesting and Storage. In addition to high yields and good adaptability, ease of cultivation has helped develop the importance of cereal crops. Sowing and reaping operations have been mechanized to a point where large areas are sown and the grain is harvested quickly and efficiently by use of such machines as the self-propelled combined harvester. World-wide use of cereal grains for food has resulted in part from the ease with which they can be stored. Under ideal conditions, grain that is sound and dry can be kept for several years without loss of quality; and even under poor conditions grain can usually be stored for several months and still be fit for food.

Grain stores best when it is as dry as possible (not over 16 per cent moisture for sack, or 14.5 per cent moisture for bulk) to prevent heating caused primarily by growth of microflora universally present on all grains; when it is protected from moisture leaks and from moisture increase in a cold spot by translocation from a hot spot; when it is cool and protected from heat of the sun, etc.; when it is mature and sound; when it is clean and free from cracked kernels, chaff, straw, dust, earth, and especially weed seeds; and when it is free from and protected from attacks by insects and rodents².

Insects are a greater problem in hot countries than in more temperate climates, especially when grain is stored in sacks. Fumigation with mixtures of ethylene dichloride and carbon tetrachloride, with methyl bromide, and with fumigants of other types, is widely practiced. Systematic fumigation every few weeks, and use of dusts to inhibit reinfestation, is often required for sacked grain stored in hot climates. Bulk storage can generally be made relatively insect-proof, facilitates fumigation, and also reduces the surface presented to insects that do not penetrate deeply.

The type of storage selected depends on amount of grain, storage time, need for maintaining quality (e.g., requirements of enforced government grading), need for improving quality (by drying, cleaning, or mixing), on frequency and speed requirements in filling and emptying and on general economics. Economics are generally paramount. No generalization can be offered; a home-made clay vessel with lid, and plugged outlet at bottom, holding 5 bushels, in a hut in India, may be as sound a solution of a practical problem as a 5-million bushel, concrete elevator, in some city in the United States.

With this general background, each of the cereal grains will be considered individually with respect to the current status of production, processing and utilization. Specialty types of cereal products will then be discussed followed by a summary of non-food uses for cereals and cereal products.

WHEAT

General Uses of Wheat

Pound for pound, the world production of wheat is greater than that of any other cereal grain. Unlike most other cereals, wheat is used principally for human food and thus assumes a particularly important position among the cereals. Its main food use is in the manufacture of flour for making bread, biscuit and pastry products although a small proportion is converted into breakfast cereals and raw materials for the macaroni-making industry. The production of wheat flour is by far the largest milling industry in the United States, although a decrease in yearly per capita consumption from 153.2 lbs. in 1946 to 129.7 lbs. in 1952 is reflected in a drop in annual wheat ground from 695 million bushels to 520 million bushels over the same period of time⁴⁰.

Classes of Wheat and Their Cultivation

Wheat is grown extensively throughout the world. It is adaptable to a wide range of soils and climates but, in general, the main wheat belt lies between latitudes of 30° and 55° in the North Temperate Zone and 25° and 40° in the South Temperate Zone where the annual rainfall averages between 12 and 45 inches. In the United States, five classes of wheat are commonly

TABLE 14-3. WHEAT CLASSES PRODUCED IN THE UNITED STATES

Class	% Total production ^a	Leading producing states
Hard red spring.....	14	North Dakota, South Dakota, Montana
Hard red winter.....	55	Kansas, Nebraska, Oklahoma, Texas
Soft red winter.....	15	Ohio, Indiana, Illinois
Durum.....	2	North Dakota, South Dakota
White.....	14	Washington, Oregon, New York, Michigan

^a Calculated from production figures for 1952, Agricultural Statistics, 1953, U.S.D.A.¹

grown. These are shown in Table 14-3 with the leading producing states and the percentage of total United States wheat production made up by each class. Winter wheats are sown in the fall for harvesting the following summer and generally have higher yields than spring wheats wherever they can survive the winter.

Methods of cultivation and harvesting of wheat have come a long way since the first prehistoric interest in wheat as food⁵⁸. The combined harvester has been the most recent development and has resulted in truly extensive growing of wheat in the United States Great Plains. Fleets of self-propelled units now move into Texas and Oklahoma at harvest time and follow the ripening grain northward into the Dakotas.

Varieties

The new harvesting methods have modified the emphasis on certain desirable varietal characteristics. In addition to the ever-present demand for high yield, high test weight, disease resistance, and good milling and baking quality, early maturing varieties are desired with good straw strength and less tendency toward lodging and shattering in the field. Plant breeders are continually at work on new varieties which embody these desirable features. A classification and description of wheat varieties has been prepared by Bayles and Clark⁵.

Processing of Wheat to Flour

There are several excellent descriptions of modern wheat processing methods^{17, 23, 30, 52, 56}. Basically, the flour milling process has changed little since the adoption of the Hungarian "long system" of roller milling in the middle of the 19th century. The aim in wheat flour manufacture is the separation of endosperm from the bran and germ as completely as possible, followed by reduction of the endosperm to the particle size of flour. This is accomplished by a series of steps involving wheat selection and blending, cleaning, tempering, breaking, bolting or seiving, purification and reduction. To this must be added maturing and bleaching, "diastating" where neces-

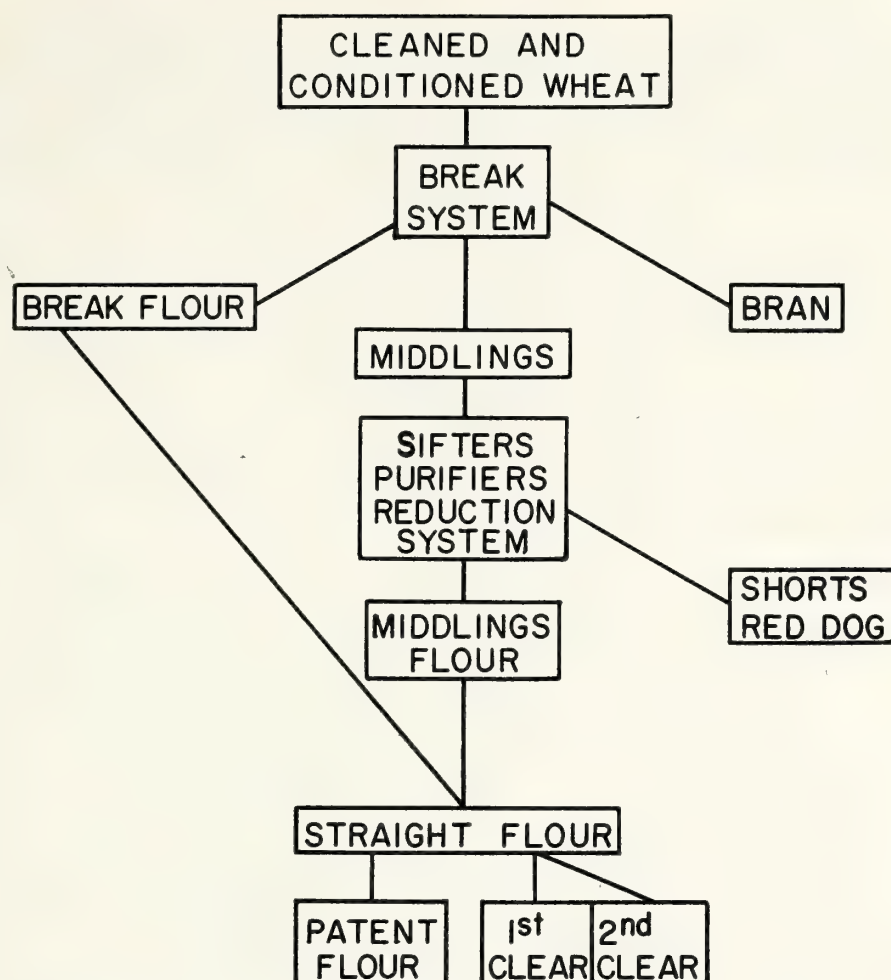


Figure 14-1. Schematic diagram of the milling system.

sary, and vitamin and mineral enrichment. Figure 14-1 is a simplified general diagram of the milling system.

Wheat Selection and Blending. Wheat selection and blending according to quality is an essential phase of modern milling since chemical composition and quality of individual lots of wheat will vary with variety and environmental conditions. In addition to the usual practice of blending wheat to specified analytical values and baking tests, application of physical dough testing methods to wheat quality specifications has helped make it possible to select and blend wheats to give a flour which will meet required performance standards. Whereas past variations in flour quality were compensated for by adjustments in the baking formula, the tendency today is to insist on performance in a given formula—a situation which results in part from the special requirements placed on flour characteristics and uniformity by the increasing use of prepared mixes.

Since the passage of the Food, Drug and Cosmetic Act in 1938, increasing emphasis has been placed on the grinding of clean insect-free wheat. Considerable research on this problem has resulted in a machine which reveals in an X-ray photograph the extent of infestation in a sample of wheat^{31, 32}.

This type of machine is now used in many of the larger mills and terminal elevators for detecting hidden infestation and may be valuable in detecting weather checks or cracks in weathered kernels³³. Another area of recent research interest is the electron treatment of wheat and flour to stop insect reproduction⁴.

Wheat Cleaning. The change to combined harvesting methods has necessitated some changes in wheat cleaning methods. Many machines have been developed for dry cleaning of wheat, most of which involve the use of sieves, air blasts, disk separators or a scouring apparatus. With the advent of the combine, wheat from the field generally contains more foreign material and more efficient cleaning equipment with greater emphasis on the stoning operation has been developed.

Many American mills are equipped with wheat washers in which the wheat is scrubbed under a flowing stream of water after which the excess water is removed in a centrifuge or "whizzer." Wheat washing, however, is not widely used because of operational problems which have not been overcome. Since good preliminary dry cleaning is essential even when wheat is washed, more efficient cleaning of wheat preparatory to milling remains a problem of current interest.

Wheat Conditioning. Conditioning or tempering of the wheat involves an addition of water (final moisture content usually 15 or 16 per cent) to the grain, followed by a period of standing sufficiently long to secure maximum toughening of the bran with optimum mellowing of the endosperm. Heat has been used in conjunction with water in the conditioning process, particularly in Europe, but this practice is not widely used in the United States.

Grinding and Sifting. Breaking, sieving, purification and reduction are processes used in the separation of the endosperm from the bran and the germ followed by its gradual reduction in particle size to the fineness of flour. Break rolls, which crack the kernel and remove chunks of endosperm from the bran, are pairs of corrugated rolls which rotate toward each other at a speed differential of about $2\frac{1}{2}$ to 1. Reduction rolls are usually smooth rolls which revolve toward each other at a speed differential of about $1\frac{1}{2}$ to 1. After each passage of stock between a pair of rolls, the ground material is sifted and classified according to particle size, degree of purification, etc. Each grinding operation yields a certain amount of material with the fineness of flour which goes to make up a "mill stream." Large mills may have 30 to 40 mill streams which are subsequently blended in different ways to give different grades of flour.

Developments in flour milling during recent years have been concerned chiefly with refinements in the system. A desire for greater operation efficiency induced by higher ingredient costs and the recent emphasis on mill

sanitation has stimulated improved design of milling equipment. Materials handling has received attention with particular consideration for bulk storage and transport of flour. Where bagging of flour is necessary, automatic high speed packers have eliminated much of the labor involved. Improved dust collecting has been another refinement of current interest. Research has discovered uses for flour dust which makes it more worthwhile to collect. Efforts to improve employee working conditions and ordinances concerning air pollution control have also stimulated progress in this area.

Pneumatic Milling. Probably the most widely discussed development is that of pneumatic milling⁵⁷. Transporting materials with pneumatic systems is far from being a new idea, but successful application to the flour milling system has come only by virtue of recent knowledge gained in research in aerodynamics⁵¹. Different mill stocks have been studied in air streams to determine the correct mixing proportions and velocities for each of the stocks. Sifting is much easier in the pneumatic system and milling results have been found to be excellent. The space occupied by this type of mill is much less than in an ordinary installation and there is considerable simplification of elevating, spouting, and dust collecting problems. Most of these systems have been installed in Europe where existing mills had been destroyed or were obsolete, but their operation is being watched with interest by millers in the United States.

Air Classification. Reports on the properties of various particle size fractions of flour have stimulated interest in some quarters concerning the air classification of flour⁵⁴. The application of air classifiers used for cement or coal to the fractionation of flour has not met with wide acceptance although such operations may have future value in conjunction with pneumatic milling systems.

Impact Milling. In the search for more efficient grinding machines, attention has been given to the principle of impact grinding¹⁹. This operation is a significant departure from roll systems and impact milling machines of various designs are being used in some mills. The Entoleter, widely used for some time for control of infestation, has been adapted to impact milling and is the most popular of the impact mills.

Flour Treatments and Adjuncts. When freshly milled wheat flour is stored, certain incompletely understood changes take place which result in a gradual improvement in color and in baking quality. Chemical maturing and bleaching agents are normally added to flour in order to accelerate these changes. Oxides of nitrogen, chlorine, benzoyl peroxide and chlorine dioxide are some of the chemicals used¹⁸. Chlorine dioxide (Dyox) and benzoyl peroxide (Novadelox) are now almost universally used in bread flours in the United States. Benzoyl peroxide is a bleaching agent only, while

TABLE 14-4. PROXIMATE COMPOSITION OF WHEAT AND SOME OF ITS MILLED PRODUCTS

Product	Moisture (%)	Protein (N × 5.7) (%)	Fat (%)	Fiber (%)	N-free extract (%)	Ash (%)
Whole grain ^b						
Hard spring.....	9.9	15.8	2.2	2.5	67.8	1.8
Hard winter.....	10.6	13.5	1.8	2.8	69.2	2.1
Soft winter.....	10.8	10.2	1.9	2.1	73.2	1.8
Pacific soft.....	10.9	9.9	2.0	2.7	72.6	1.9
Flour products ^c						
Graham.....	11.0	13.0	2.0	1.8	70.6	1.6
Straight.....	12.0	11.2	1.1	0.4	74.8	0.5
All-purpose patent.....	12.0	10.8	0.9	0.3	75.6	0.4
Bread patent.....	12.0	11.8	1.1	0.3	74.3	0.5
Cake patent.....	12.0	8.3	0.8	0.2	78.3	0.4
By-products ^b						
Bran.....	10.1	15.5	4.2	8.9	55.1	6.2
Shorts.....	11.3	16.9	4.2	7.1	56.0	4.5
Low-grade flour.....	11.6	15.4	1.9	0.5	69.7	0.9
Germ.....	9.2	31.1 ^a	9.7	2.6	42.2	5.2
Red dog.....	11.0	18.2	3.6	2.6	61.9	2.7

^a N × 6.25.
^b Selected from Morrison³⁹.
^c Selected from Chatfield and Adams⁷.

chlorine dioxide and chlorine are both maturing (developmental) and bleaching agents. In cake flours, chlorine gives certain beneficial affects not obtainable with any other agent. Potassium bromate is widely used for its maturing effects, but since its action is almost entirely limited to the dough stage it is usually not considered with flour maturing agents.

The amylase activity in flours is frequently too low for optimum baking performance. This condition is rectified by the addition, either at the mill or at the bakery, of small amounts of malted barley flour, malted wheat flour, or, more recently, fungal amylase preparations.

Premixed concentrates of vitamins and minerals are commonly added to flour in accordance with the enrichment program discussed previously. Soda and various phosphates also appear in phosphated or self-rising flours for special purposes.

Flour Quality

Table 14-4 gives the proximate analysis of wheat and some of its milled products. In wheat and flour technology, the term quality is a purely relative one and denotes the suitability of the material for some particular purpose. While there are many complex factors involved in flour quality, the quantity of proteins and their physical properties are of prime impor-

tance and marked differences in both factors are found in different flours. Physical properties of the protein as measured by physical tests of doughs have become important measures of flour quality. Laboratory instruments such as the Brabender Farinograph and Extensograph have been designed for testing physical properties of doughs and are widely used throughout the milling industry in both quality control and research. Basic properties of cereal proteins continue to be subjects of current research interest.

The properties of starch and other carbohydrates in wheat and other cereals have been the subject of other recent investigations, particularly with reference to biochemical changes during bread storage and the susceptibility of starch to enzymatic degradation. Recent studies have shown that flour stability may be enhanced by increasing the degree of refinement, eliminating treatment with oxidizing improvers, and decreasing the moisture content below normal commercial levels¹¹. Other areas of interest in flour and wheat research include the influence of hydrolytic and oxidative enzymes, oxidation-reduction systems, flour and wheat pigments, the influence of salts on flour quality, and others.

Food Uses of Wheat Products

Bread and Other Yeast-raised Products. Basically, bread manufacture requires only four ingredients—wheat flour, water, yeast, and salt. Flour, particularly hard wheat flour, with its unique gluten protein, supplies the structural basis for the finished bread; water is necessary for the doughing procedure; adequate leavening is dependent on production of carbon dioxide by yeast action on fermentable sugars; and salt is present to tighten the dough and check wild yeast growth. Bread quality, flavor and nutritive value are improved by additional ingredients. With percentages based on flour as 100 per cent, other ingredients in a typical white bread formula include water, 64 per cent; yeast, 2 per cent; salt, 2 per cent; sugar, 6 per cent; nonfat milk solids, 6 per cent; shortening, 4 per cent; and 0.2 to 0.5 per cent of dough conditioners⁴⁶. In practice, the chief difference between various yeast-raised products such as whole wheat bread, white bread, white rolls, and sweet goods is in their richness or the amount of sugar, shortening, eggs and milk used.

Two general procedures are used for baking bread^{6, 46}. In the straight dough method, all ingredients are mixed in one operation while the sponge and dough procedure involves two distinct mixing steps. A portion of the flour (50 to 70 per cent), all the yeast, yeast foods and sufficient water are mixed to form the sponge which is permitted to rise to a desired height. The sponge is then broken up and remixed with the balance of formula ingredients to form the dough. The sponge dough procedure has been preferred by bakers because of savings in yeast requirements, improved volume, grain and texture, and greater flexibility in baking schedules.

An outstanding development in baking technology has been the recent introduction of an automatic bread-making process³ in which a prefermented yeast solution is mixed with other ingredients and the resulting dough is discharged into pans ready for proofing and baking. All ingredients are fed automatically into a closed system, and, from the start of mixing until the dividing of the dough into pans automatically and continuously, about two minutes elapse. Several installations have been made in bakeries and, if practical, this operation may revolutionize the baking industry.

Another development which has created considerable interest is called the stable ferment baking process and involves some of the principles behind the automatic process²⁸. The use of a stable preferment eliminates the sponge stage of the conventional baking process and is reported to result in improvements in product quality and uniformity. Considerable reductions in labor and equipment are also expected.

Chemically Leavened Products. Chemically leavened flour products include cakes, cookies, biscuits, doughnuts, etc., which depend upon the reaction between soda and an acid leavening ingredient to produce the carbon dioxide which will make the product light. A few products such as angel cake depend entirely on air for leavening. Flours for these purposes are normally milled from soft winter wheat varieties which possess relatively low protein contents⁴⁶. The soft red winter wheats are sometimes blended with soft white varieties to get the properties desired. High absorption or water-carrying capacity, low protein content, fine granulation, and chlorine bleach to a pH of 5.0 to 5.2 appear to be desirable in cake flour

Alimentary Pastes. Durum flour or semolina is used primarily for products such as macaroni, spaghetti, and noodles which are referred to as alimentary pastes. Semolina, the coarsely ground, highly purified middlings stock is regarded as the prime material for macaroni manufacture. Macaroni, which comes in 100 to 124 shapes and sizes, is made from a blend of semolina (or flour), water, and in some cases, salt. Most of these products are manufactured in automatic machines which mix, knead, and form the product into the desired shape. Automatic pressers will turn out 800 to 1200 pounds of product per hour. The product then enters drying rooms where 8 to 72 hours of drying is required depending on the type of product.

CORN

Production and General Uses of Corn

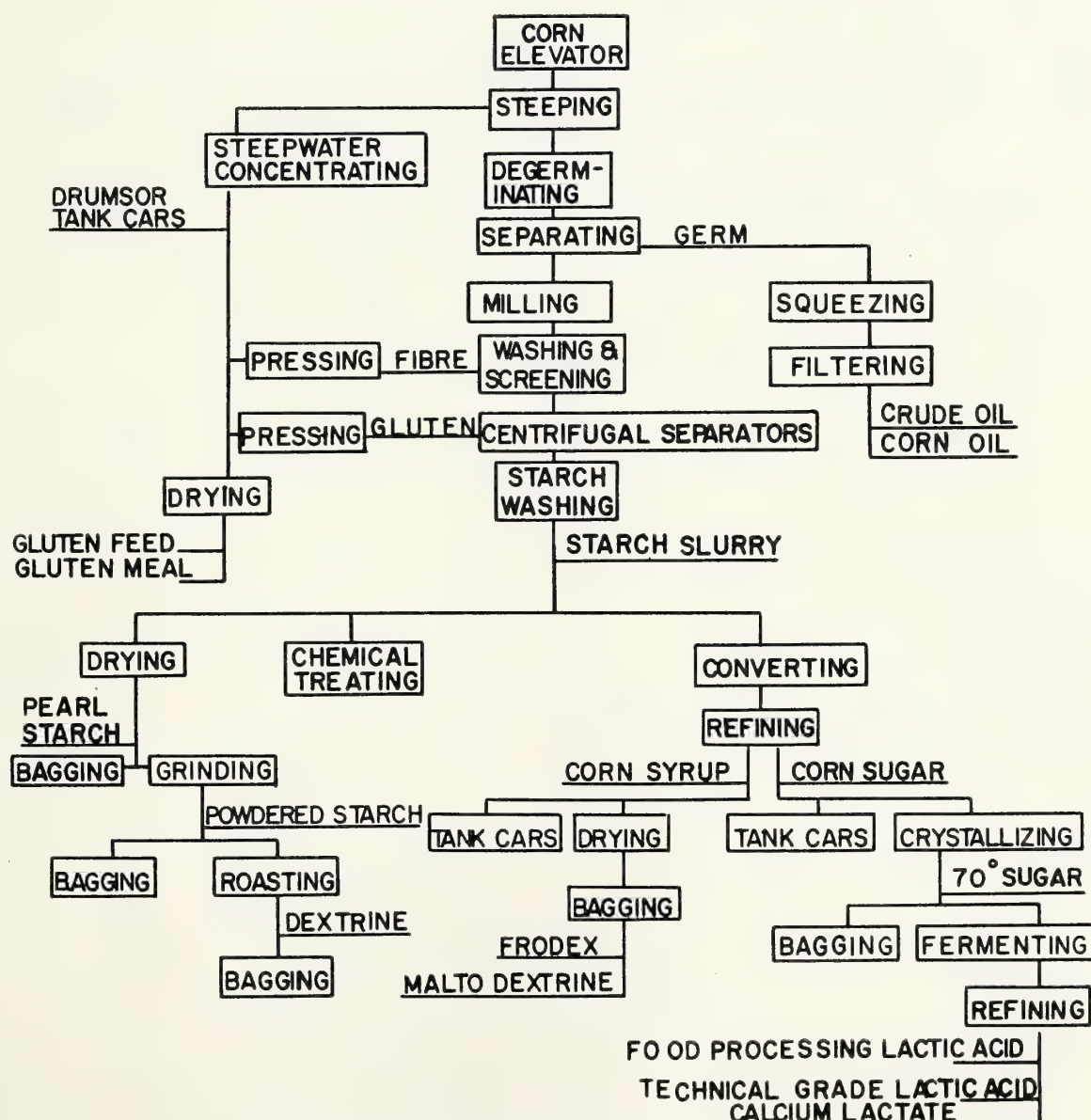
The principal area of commercial production of corn is in the warm, moist "corn belt" of the United States, which includes Iowa and Illinois and parts of all adjoining states. The widespread use of hybrid corn in recent years has resulted in marked improvements in yield and quantity of corn for specific purposes. Certain varieties of corn have been developed which pro-

duce a so-called waxy starch with physical properties corresponding closely to those of root starches from which tapioca is made. Interest of plant breeders continues in this area.

Of the tremendous annual corn crop of the United States (see Table 14-1), only about 4 per cent is processed by the corn refiners. Three other industries—the dry millers who make corn meal and breakfast foods, the feed manufacturers, and the distillers—take, collectively, about 13 per cent more. Perhaps 3 per cent is exported and the rest stays on the farms where it is fed to livestock and poultry¹⁰.

Processing

Wet Milling. In the wet milling process the object is to separate the various components of the grain primarily for industrial utilization. Manufacturing techniques have been improved, new uses for all wet milled prod-



(Courtesy of American Maize-Products Co., Roby, Indiana)

Figure 14-2. Functional flow chart of a corn refining process.

ucts have been discovered, and, as a result, there is virtually no waste material in the corn wet milling process. A functional flow chart of a modern corn wet milling process is shown in Figure 14-2. Most of the operations shown have been described¹⁷, but one significant recent change is the introduction of centrifugal separators in place of the starch tables. This advancement and the replacement of wood and steel construction with stainless steel have markedly improved the sanitation picture. There has been an improvement also in the drying technique. A flash drier is used wherein the granulated wet starch cake is dried in combustion gases formed by burning natural gas or propane. This process results in shorter drying time with a minimum change in starch properties.

Dry Milling. Corn is ground for human consumption by two general methods which are adequately described by Geddes¹⁷. The old process involves grinding the grain to a coarse meal between mill-stones. The product is essentially a whole corn product which has a rich, oily flavor and deteriorates rapidly.

The new process of corn milling is carried out with steel rolls along lines similar to those described for the milling of wheat. The object is to remove the bran and germ and to recover the endosperm in the form of hominy or corn grits, coarse meal, fine meal, and corn flour. The relative yields of the various mill products vary depending upon whether the main objective is the production of grits or meal and whether the corn is degermed before

TABLE 14-5. PROXIMATE ANALYSIS OF CORN AND SOME OF ITS MILLED PRODUCTS

Product	Moisture (%)	Protein (%)	Fat (%)	Fiber (%)	N-free Extract (%)	Ash (%)
Whole grain ^a	11.0	10.0	4.3	2.1	71.3	1.3
Food Products ^a						
Corn flour.....	12.1	7.9	2.2	0.7	76.3	0.8
Corn germ.....	9.1	14.5	20.8	5.1	44.8	5.7
Corn, hominy.....	11.4	8.5	0.8	0.4	78.5	0.4
Corn meal, whole.....	12.0	9.1	3.7	2.0	71.9	1.3
Corn meal, degerminated.....	12.0	7.9	1.2	0.8	76.6	0.5
By-products ^b						
Corn bran.....	9.4	9.7	7.3	7.4	39.4	4.9
Corn feed meal.....	11.4	9.8	4.7	2.9	69.2	2.0
Corn germ meal.....	7.0	19.8	7.8	8.9	53.2	3.3
Corn gluten feed.....	9.1	25.5	2.7	7.6	48.8	6.3
Corn gluten meal.....	8.6	43.1	2.0	4.0	39.8	2.5
Corn oil meal.....						
Old process.....	8.3	22.3	7.8	10.3	49.0	2.3
Solvent process.....	8.3	23.0	1.5	10.4	54.6	2.2

^a Whole grain and food product analyses abstracted from Chatfield and Adams⁷.

^b By-product analyses compiled from Morrison³⁹.

grinding. In milling of corn for grits and meal by the degerminating process, the following yields are typical: grits, 52 per cent; meal and flour, 8 per cent; hominy feed, 35 per cent; and crude corn oil, 1 per cent¹⁷. There is a shrinkage of about 4 per cent which results largely from differences in moisture content of the corn and various milled products. Table 14-5 gives the proximate composition of corn and some of its milled products. Sanitation has been a problem in the corn dry milling industry and improved cleaning and storage methods have resulted in a much more efficient removal of such contaminating materials as rodent hairs and excreta.

Wet Milled Products and Uses

In general, corn wet milling yields 3 per cent oil, 16 per cent water, 26 per cent feed, and 55 per cent starch. The finished products are used by a host of food and nonfood industries—more than the products from any other cereal. Table 14-6 lists some of the main food uses. Corn starch and products derived from corn starch—sugars, sirups, and dextrans—have the widest variety of uses. The technology of these products is progressing at a rapid

TABLE 14-6. SOME PRODUCTS OF CORN WET MILLING AND THEIR USES

Product	Food uses	Industrial uses
Germ		
Oil meal	Livestock feed	
Foots		Soap, glycerin, leather dressing, etc.
Refined oil	Salad and table oils, cooking oils, mayonnaise, oleomargarine, pharmaceuticals	
Steep water	Antibiotics, solubles for feed, phytic acid, yeast food, inositol, etc.	
Gluten and hulls	Livestock and poultry feed	
Starch	Corn starch, confectionery, chewing gum, bakers' baking powder, brewing	Textiles, laundry, paper and paper boxes, explosives, cosmetics, adhesives
Sirup	Bakery products, canned fruits, ice cream, confectionery, soft drinks, chewing gum, mixed sirups, brewing, jams and jellies	Textiles, leather tanning, adhesives, pharmaceuticals, paper (special types), tobacco
Sugar	Bakery products, pharmaceuticals, carbonated beverages, jams and jellies, ice cream, canned foods, meat products, confectionery, dietetics, dessert powders	Rayon, tanning, fermentation, brewing, vinegar, caramel color, fermentation products, tobacco

rate and new products are being developed as well as new uses for existing products.

Corn Sugars. Corn sugars and sirups are no longer considered as substitutes for sucrose, and are applied because of functional properties rather than just sweetening agents. Dextrose or glucose can be obtained as a white crystalline product which improves flavor, texture, color, and handling properties in many finished products. It has become essential in many foods and is also entering the chemical and other nonfood fields.

Crude corn sugars are amorphous materials which contain dextrose, reversion products (sugars of higher molecular weight than dextrose) and small quantities of sodium chloride and protein. The products available are light-brown to yellow in color and have a bitter-sweet flavor. They are used in the brewing and tobacco industries, for the production of certain types of vinegar and other organic acids, and in several nonfood fields.

Corn Sirups. Corn sirups are concentrated solutions of various carbohydrates obtained from corn starch by partial hydrolysis, clarification, decolorization and evaporation to the desired solids content. All corn sirups, regardless of the degree of hydrolysis or conversion are mixtures of the same basic ingredient, i.e., dextrose, maltose, higher sugars, dextrans and water. Corn sirup may be classified into four main groups based on degree of conversion as measured by the dextrose equivalent (D.E.). These are given in Table 14-7. Most products in these four groups can be obtained as solids for specific purposes.

Corn Starches. Corn starch is the most abundant of all commercial starches and is the raw material for a large variety of specialty starches and converted products, many of which have little or no food use. Heavy and thin boiling starches refer to the viscosity of the cooked paste and are available in a wide range of viscosities. Heavy boiling starches are used principally in textile and paper fields while acid treated thin boiling starches are widely used in gum confections and laundry starches. Other degraded starch products are obtained by heat treating or roasting under various conditions to prepare dextrans or British gums, which are important items

TABLE 14-7. THE GENERAL TYPES OF CORN SIRUPS AND THEIR USES

Corn sirup product	D.E.	Uses
Low conversion	Less than 40	Infant foods, chewing gum, beer, fountain sirups, soups, cake frostings, condiments
Regular conversion	40-49	Confectionery, cakes, pie-fillings and crusts, cereals, frostings, ice cream, jams, jellies, etc.
Intermediate conversion	50-57	Confectionery, table sirups, bakery items, pharmaceuticals, etc.
High conversion	58 or over	Ice cream, table sirups, jams, jellies and confections

in library pastes and adhesives for packaging and labeling. Much research has been done with roasted starches and major improvements have been made. Study of the action of enzymes on starch has also resulted in commercial degraded starch products and has accomplished much in the clarification of starch structure.

In the past ten or twelve years, starch derivatives have found extensive application due to their increased resistance to breakdown or hydrolysis in acid media and their improved ability to withstand low temperature storage in cooked form. Cross-linked or inhibited starches result from treating starch with a chemical which reacts with the hydroxyl groups to introduce replacements for such groups. If the replacement is bi- or polyfunctional, the starches are capable of reacting with more than one hydroxyl group to form cross-linkages or bridges from one starch molecule to another with resulting changes in starch properties. Derivatives applicable to baking, salad dressing, canned food and other food fields are those with a very low degree of substitution.

Amioca or waxy corn starches are also available in any of the above modifications. Waxy corn starch is more like tapioca than like a cereal starch and has many applications in both food and industrial fields. Even with the great advances in methods for modifying starches, there still remain applications for starches of different botanical origins.

OATS

Distribution and Varieties

Oats are grown throughout the world but North America, Europe and Russia are the greatest producers. While they are grown throughout the United States, the chief producing areas conform closely to the North Central "corn belt" but extend farther north. In the North Central states, white and yellow oats are milled, but red oats are more prevalent in the South Central area. Oat milling is one of the leading cereal industries in the production of breakfast cereals; the per capita consumption of oatmeal is about 4.0 pounds yearly¹⁵.

Present varieties of oats are resistant to most races of rust and smut as a result of a world wide search in the United States in the late 1920's to find resistant oat varieties. Varieties were developed which are not only disease resistant, but which have stiffer straw, heavier test weight, thinner hulls, and other desirable characteristics which make them more acceptable to the grower and the oat miller. The problem of developing new varieties is a continuing one however because of the appearance of various new rust strains from year to year.

Processing

The milling of oats into rolled oats has been described by Geddes¹⁷. Essentially the process consists of cleaning, drying, dehulling, separation of groats, groat steaming and rolling. The so-called "old fashioned" or "regular" rolled oats are made from whole groats. The more recent "quick" rolled oats, so-called because they are quicker cooking, are made from groats which have been cut with rotary cutters into about three pieces, then steamed and rolled to make a smaller and thinner flake. Regular rolled oats require about 10 to 15 minutes of cooking over a direct flame while quick rolled oats require about 2½ to 5 minutes. There is no difference in food value between regular and quick rolled oats since they are both made from whole grain.

The most important change in milling oats in recent years has been the introduction of impact hulling. Formerly hulling was done by means of stones but impacting machines are now used. Essentially the impact huller consists of a disc revolving at high speeds upon which dried oats are fed and impacted against a rubber ring lining the stationary housing of the machine. Oats travel in a path parallel to their long axes and the hulls are split off as they strike the rubber walls. By this method of hulling more of the whole groat is retained for food than with stone hulling since with the latter method, much of the oat germ was lost by abrasion.

The two most important steps in the milling process that contribute to the flavor of rolled oats are drying of the oats and steaming groats. Drying contributes a toasted, nutty flavor; steaming reduces enzymatic activity to a minimum so that lipolytic activity is almost completely eliminated. Rolled oats contain about 7 per cent fat. If lipolysis is allowed to occur a bitter flavor will develop in the finished product⁶³.

Nutritive Value of Oats and Oat Products

Composition. The proximate composition of oats and oat products is given in Table 14-8. Oats are high in protein and oil compared to other grains. The distribution of fat in oat groats is different from other cereal grains in that the endosperm is relatively much higher in fat. An example of the distribution of fat in oats and oat products is given in Table 14-9.

Oats contain enzyme systems common to other cereal grain such as amylases, lipases, esterases and proteinases. However, oats have been shown to exhibit relatively high lipase and proteinase activity, compared to other grains. Because oat endosperm carries appreciable portions of fat, lipolytic activity of rolled oats as a food is of paramount importance. When groats are properly dried and steamed the flakes will remain low in free fatty acids for long periods of time. This stability has been attributed to the inactiva-

TABLE 14-8. PROXIMATE COMPOSITION OF OATS AND OAT PRODUCTS^a

Product	Moisture (%)	Protein (%)	Fat (%)	Fiber (%)	N-free extract (%)	Ash (%)
Whole grain.....	9.8	12.0	4.6	11.0	58.6	4.0
Food products						
Oat meal or rolled oats.....	9.2	16.0	5.5	2.7	64.2	2.4
Groats.....	9.6	16.3	6.1	2.1	63.7	2.2
By-products						
Oat clippings.....	7.8	8.8	2.3	25.3	44.9	10.9
Oat middlings.....	8.6	15.9	5.2	3.3	64.6	2.4
Oat mill feed.....	7.6	5.6	1.8	27.9	50.8	6.3

^a Selected from Morrison³⁹.

tion of lipases during the drying and steaming process prior to rolling the flakes.

Rolled Oats in the Diet. Rolled oats is essentially a whole grained product and has a higher crude protein content than other cereal foods. Only the hull is removed and the germ fraction containing protein of superior nutritional quality is not lost. This fact helps explain the superior growth promoting value of protein in rolled oats compared to other cereal products^{34, 47}. The results of growth tests using weanling rats indicate no significant difference in quality between the proteins of groats and rolled oats made from them⁴⁷.

TABLE 14-9. DISTRIBUTION OF FAT IN OAT GROATS^a

Portion of goat	Per cent by weight	Per cent fat, ether extracted (dry basis)
Germ (hand dissected).....	7.0	11.2
Germ-free groats.....	93.0	5.8
Germ plus bran coats.....	31.0	7.4-9.0
Endosperm.....	69.0	6.2-6.7

^a From the Quaker Oats Co.⁴⁷.

BARLEY

General Uses of Barley

Barley is predominantly a feed grain. Of the estimated 370-million bushel yearly crop in the United States, about 70 per cent is used for livestock feed where it is particularly valuable in hog rations. A relatively small proportion is used for pearling and milling and the remainder, about 100 million bushels, is converted into malt.

Distribution and Harvesting

Barley grows in nearly all temperate climates and is said to be more widely distributed than any other crop⁵³. It is an annual crop having both

winter and spring varieties, but thrives best in cool weather. Production in the United States is heaviest in the North Central states of North Dakota, South Dakota, Minnesota, and Nebraska and California. Russia, China, the United States and Canada are the leading barley producing countries.

Harvesting should be done only when the grain is fully ripe for best yields and quality. In some areas of the world, barley is still harvested and threshed by primitive methods (as are a number of other crops); however combining from standing grain or windrows is widely used in the United States and Canada.

Varieties and Quality

Barley destined for malting must meet standards considerably more stringent than those imposed on feed barley. Premiums are usually paid for satisfactory malting barley of which about 90 per cent is of the midwestern six-row Manchurian type. Predominant varieties are Kindred and Montcalm. Western six-row barleys are used for malting in the western states and, in addition, some western two-row barley varieties are malted and used in making European type beers. Maltsters place great emphasis on not only the germination capacity of barley, but also on germination vigor. In addition to desirable malting qualities, adequate resistance to disease, good yield potential, and satisfactory area adaption are obvious characteristics of suitable barley regardless of use. Plant breeders under both federal and state sponsorship are actively engaged in the development of improved barley varieties.

Processing

Milling. Two types of barley milling are described by Geddes¹⁷—pearling and milling to grits and flour. Most of the barley which goes into human food is consumed in the forms of pot and pearl barley. These are manufactured by gradually removing the hull and outer portion of the barley kernel by abrasive action. Disks, usually coated with silicon carbide or emery, grind off the outer layer of the kernel by revolving within a perforated cylinder. After each pearling, the grain is sifted, aspirated and cooled before being sent to the next pearler. Three pearlings result in a product sold as pot barley. After five or six pearlings, all of the kernel coating and practically all of the embryo are removed, and the product is marketed as pearled barley. One hundred pounds of barley will yield about 65 pounds of pot barley or 35 pounds of pearled barley.

Milling for barley flour or grits is accomplished by a roller milling, bolting, and purification process similar to that used in milling flour from wheat. In larger mills, the hulls are usually removed before milling by a pearling process. Table 14-10 gives the proximate composition of barley and some of its products.

TABLE 14-10. PROXIMATE COMPOSITION OF BARLEY AND SOME OF ITS MILLED PRODUCTS

Product	Moisture (%)	Protein (%)	Fat (%)	Fiber (%)	N-free extract (%)	Ash (%)
Whole grain ^a (hull-less).....	10.2	12.8	2.1	2.7	70.1	2.1
Food products ^a						
Flour.....	10.0	10.2	1.7	0.7	76.2	1.2
Pearled, pot or scotch.....	10.8	8.7	1.0	0.8	77.5	1.2
Pearled, light.....	11.1	8.2	1.0	0.5	78.3	0.9
By-products ^b						
Feed (high grade).....	9.7	13.5	3.5	8.7	60.5	4.1
Malt.....	6.6	12.7	2.1	5.4	70.9	2.3
Screenings.....	11.4	11.6	2.7	9.1	61.3	3.9
Brewers grains, dried.....	7.1	27.6	6.5	14.3	40.9	3.6

^a From Chatfield and Adams⁷.

^b Selected from Morrison³⁹.

TABLE 14-11. USES OF BARLEY PRODUCTS

Process	Product	Uses
Pearling	Pot or Scotch barley	Soups, dressings
	Pearled barley	Soups, dressings
	Flour and feed	
Milling	Flour	Baby foods, food specialties
	Grits	
	Feed	
Malting	Brewers	Beverages, brewers grains, dairy feeds, brewers yeast
	Distillers	Alcohol, distilled spirits, distillers grains and solubles for feeds
	Specialty malts (high dried, dextrin, caramel, black)	Breakfast cereals, sugar coatings, dark beers, coffee substitutes
	Malt flour	Wheat flour supplements, human food products
	Malted milk concentrates	Malted milk beverages, infant foods
	Malt syrups	Medicinal, textile, baking, breakfast cereals, candies
	Malt sprouts	Dairy feeds, vinegar, industrial fermentations

Malting. The object of malting is to germinate the grain under conditions conducive to bringing about certain desirable physical and chemical changes and involves three steps—steeping, germinating and kilning. These steps are described in detail by Dickson and Kneen¹². Cleaned barley is steeped in cold water with aeration for about 2 days or to 45 per cent moisture. After transfer to germinating equipment (drums or compartments),

humidified, temperature-controlled air is drawn through the grain during a germination period of 5 to 7 days at 60 to 70°F. At the end of the germination period, the "green" malt is kiln dried over a period of 24 hours starting at a relatively low temperature which is raised as the grain becomes drier.

Uses of Barley Products

Table 14-11 gives a list of uses of barley products⁵³. Most of the uses of malt take advantage of the high level of starch-splitting (alpha-amylase and beta-amylase) and protein degrading (protease) enzymes which are utilized under proper conditions of pH, temperature, and time to give the desired end product. In recent years about 80 per cent of the malt production has been used for manufacturing beer. From 10 to 15 per cent of malt is distillers malt used for the production of alcohol, distilled spirits and whiskey; the remaining uses of malt involve only 5 to 10 per cent of the total production.

RYE

Production and Processing

Rye, grown in much the same areas as wheat, will survive more severe winters and produce larger yields of grain on soils of low fertility than any other cereal crop. Most rye is sown in the fall and, because of its hardiness, its chief producing area in the United States is in Minnesota, North Dakota, and South Dakota, just north of the winter wheat area. It is not an important crop in the United States, but is widely grown in North European and in the Scandinavian countries. Unlike wheat, which is almost exclusively a self-fertilized plant, but like corn, rye is open-pollinated so that much of the rye grown is not pure as to variety.

Rye is used as a feed for livestock, for the manufacture of whiskey, and for the production of flour. About half the rye produced in the United States is sold from the farm and about one third of this is ground into flour¹⁵.

Rye is milled to flour by processes similar to those used for wheat. However, since the bran adheres so tenaciously to the endosperm and the endosperm itself is "tough" and does not pulverize readily, it is impractical to clean or purify middlings, and reduction of middlings is difficult. Accordingly, reduction rolls are finely corrugated and the break rolls are set for maximum production of break flour. The highest grade of flour is produced by the first break rolls and, as the purity of flour decreases, it becomes darker with a more pronounced rye flavor. Pumpernickel flour is a coarse unbolted rye meal. The milling of rye normally yields 65 per cent light rye flour, 15 to 20 per cent dark rye flour, and 15 to 20 per cent offals.

Uses of Rye Products

The American public consider bread baked from rye flour (blends of rye and white flours) far below bread baked from wheat flour. In some European countries the production of rye bread and white bread is approximately equally divided. Rye flour proteins do not have the ability to form gluten when wet with water and, in order to obtain a yeast leavened loaf of reasonable volume, texture, grain and good eating qualities, it is necessary to blend white flour (the proteins of which form gluten) with rye flour. The inferior baking qualities of rye flour may also be partly attributed to the presence of a pectin-like carbohydrate gum.

The control of alpha-amylase is of particular importance in the manufacture of breads made with rye flours. The relatively thermostable cereal alpha-amylase may cause considerable dextrinization of starch in the oven before inactivation of the enzyme occurs, resulting in a wet, soggy crumb which may pull away from the crust. This is more of a problem in Europe than in the United States where higher percentages of rye are generally used and higher levels of alpha-amylase activity result from sprout damage due to wet harvest weather.

The proximate composition of rye flours and mill offals is given in Table 14-12. As the flour grade decreases, there is a marked increase in protein, ash, and fiber content, but the proximate composition of rye flours is very similar to that of wheat flour.

Rye is prone to attack by the fungus *Claviceps purpurea* or ergot¹⁵. The kernels are replaced by the fungus which forms purple-colored wax-like bodies (ergot) containing a series of alkaloids which are physiologically active. The sterol, ergosterol, was so named because it was first discovered in ergot. Considering its poisonous nature, ergot must be removed from rye before milling, but it has value for medicinal purposes.

TABLE 14-12. PROXIMATE COMPOSITION OF RYE AND ITS MILLED PRODUCTS

Product	Moisture (%)	Protein (%)	Fat (%)	Fiber (%)	N-free extract (%)	Ash (%)
Whole grain ^a (or rye meal)	10.0	11.2	1.7	2.0	73.2	1.9
Food products ^a						
Flour, light	11.0	8.9	0.9	1.1	78.5	0.7
Flour, medium	11.0	11.0	1.2	1.5	75.8	1.0
Flour, dark	11.0	14.9	2.1	2.1	70.0	2.0
By-products ^b						
Middlings	9.8	16.6	3.4	5.2	61.2	3.8
Feed	9.6	16.1	3.3	4.6	62.7	3.7

^a From Chatfield and Adams⁷.

^b Selected from Morrison³⁹.

RICE

Distribution

Rice is a tropical cereal grown predominantly in China, India, and other Asiatic countries. United States production is limited to southwestern Louisiana, southeastern Texas, eastern Arkansas and the Sacramento and San Joaquin valleys of California. Short-grain (or Japanese) types are grown almost exclusively in California while medium grain varieties predominate in other areas.

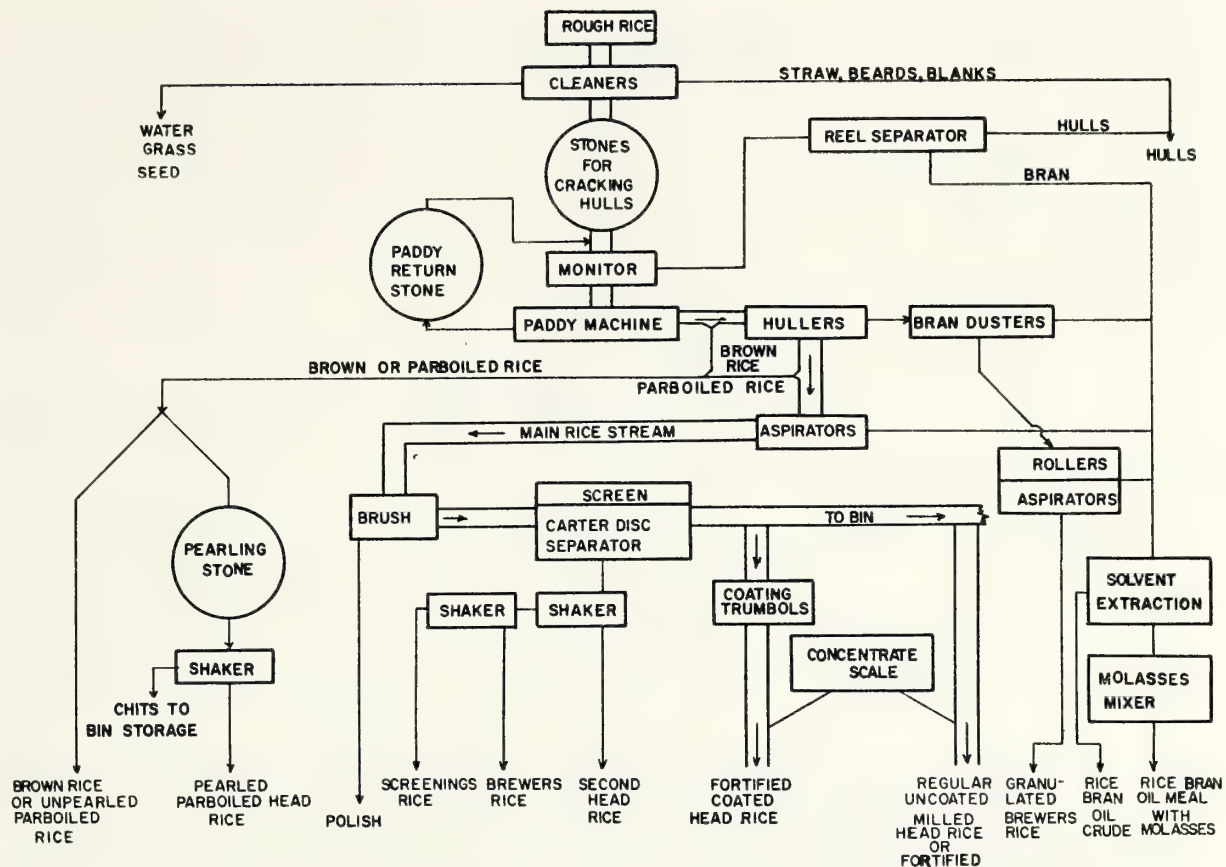
Production

Rice in the United States is grown much like other cereal grain crops except that it is irrigated and the land is kept 4 to 8 inches under water throughout the growing season. The land is prepared for seeding by plowing, harrowing and dragging either in the fall or in early spring just before seeding time. In the Southern rice growing belt, seeding is generally done with a grain drill or broadcast seeder; however, in California, the greater portion of the acreage is seeded on water by airplane. Fertilization with sulfate of ammonia and weed control with 2,4-D sprays are also accomplished by use of the airplane or helicopter. More than 400 acres per day can now be seeded in this way as compared to 25 or 40 acres by the Endgate seeder or drills pulled by a tractor.

Harvesting is done when the moisture content is between 20 and 27 per cent by direct combining after the fields have been drained. Since rough or paddy rice cannot be stored safely at moistures above 14 per cent it has been common practice in recent years to dry the grain artificially. Probably one of the outstanding advances in the rice industry has been the handling and storage of rice.

Processing

The threshed, or rough, rice kernel is enclosed in a tough siliceous hull which renders it unsuitable for human consumption. Rice milling, then, has as its objective the removal of the hull, bran and germ with a minimum breakage of endosperm. Figure 14-3 shows a simplified flow sheet for a modern rice mill giving the various end products which may be produced. The rough rice is first thoroughly cleaned by passing through several mechanical devices and then conveyed to horizontal stones for cracking the hulls. The hulls are removed by strong aspiration and the remaining hulled and unhulled grains are separated in an ingenious device called a paddy machine. The less dense, unhulled rice moves upward over the zigzag ducts of smooth steel while the hulled grains move downward. The hulled grain at this stage is known as brown or unpolished rice and has little demand as a food. Other



(Courtesy of Rice Growers Assn. of California, Sacramento, California)
Figure 14-3. Simplified flow sheet for a modern rice mill.

machines, erroneously called hullers, remove the inner bran layers and the germ and the grain is then conveyed to a brush machine where it is polished. Polished rice contains whole and broken endosperm of various sizes which are separated into head rice (whole endosperms), second head rice of various grades, screenings rice, and brewer's rice.

Uses of Rice and Its Products

Proximate Composition and Nutritive Value. The proximate composition of rice and some of its milled products are given in Table 14-13. The production of brown rice from rough rice results in an increase in the protein, fat and starch contents since the hulls are low in these constituents. Conversely, there is a decrease in crude fiber and ash contents. There is little difference between the vitamin contents of rough and brown rice but the further conversion to white rice results in a marked decrease of vitamin values as shown in Table 14-14. The fact that beriberi (due to deficiency in thiamin intake) is associated with the consumption of white rice has long been known and, as a result, there has been considerable interest in practical methods for retaining more of the B vitamins in the milled rice.

Parboiled head rice, which is a comparatively new development in the

TABLE 14-13. PROXIMATE COMPOSITION OF RICE AND SOME OF ITS MILLED PRODUCTS

Product	Moisture (%)	Protein (%)	Fat (%)	Fiber (%)	N-free extract (%)	Ash (%)
Whole grain, rough ^a	11.2	7.9	1.8	9.0	64.9	5.2
Food products ^b						
White rice.....	12.3	7.6	0.3	0.2	79.4	0.4
Brown rice.....	12.0	7.5	1.7	0.6	77.1	1.1
Flour.....	12.1	7.4	0.5	0.4	79.1	0.5
Polishings.....	9.3	11.6	10.1	2.2	61.8	5.0
Bran.....	10.7	12.5	14.4	10.7	41.8	9.9
By-products ^a						
Brewers rice.....	11.7	7.5	0.6	0.6	78.8	0.8
Brown rice.....	12.2	9.1	2.0	1.1	74.5	1.1
Bran.....	9.1	12.5	13.5	12.0	39.4	13.5
Polish.....	10.2	12.8	13.2	2.8	51.4	9.6

^a Selected from Morrison³⁹.

^b From Chatfield and Adams⁷.

rice industry, involves a process incorporating the principles of steeping, steaming and drying. While parboiling was practiced centuries ago in India, it has been developed into a mechanized continuous flow operation. This process effectively transfers the water-soluble nutrients from the hull and bran by steeping the rough rice in hot water after which the grain is exposed to heat and steam pressure while being agitated in a rotary steamer. The vitamin content of parboiled head rice is compared with brown and white rice in Table 14-14.

Another recent development has been the vitamin and mineral fortification of rice for certain markets. To accomplish this a concentrate is prepared by feeding white rice into a revolving trumble where it gets successive coatings of vitamins (thiamine and niacin), a mineral (iron as ferric pyrophosphate) and a protective coating solution. When this concentrate is later mixed with about 200 times its weight of untreated white rice, the resulting fortified rice meets the required levels yet leaves the product as white as ordinary milled rice.

Use of By-products. By-products of the rice milling process have found new food uses. One item of interest is the recent utilization of rice polishings

TABLE 14-14. B-VITAMIN CONTENT OF DIFFERENT TYPES OF RICE^a

Product	Thiamin (γ/g)	Riboflavin (γ/g)	Niacin (γ/g)
Brown rice.....	3.69	0.50	53.8
White rice (milled).....	0.60	0.25	18.1
Parboiled head rice (milled).....	2.57	0.36	39.8

^a From Kester and Jones²².

by baby food manufacturers. Much of the available supply of polish as well as some of the rice bran itself is now being utilized in this way. Of considerable interest, too, has been the solvent extraction of oil from rice bran. Rice bran oil has been refined to salad and cooking oils and has also been sprayed on alfalfa meal to control dustiness and improve the appearance of the product.

GRAIN SORGHUM

Distribution and Varieties

Grain sorghum is one of four classes of sorghum crops, the others being sweet sorghum, broom corn, and grass sorghum. This cereal thrives in semi-arid regions and is an important crop in Africa and Asia. It is also grown in the United States, Argentina, Australia, and southern Europe in areas too hot for good corn yields. In the United States grain sorghum is harvested primarily in Texas, Kansas, and Oklahoma where cultivation is as highly mechanized as wheat with custom combines moving into sorghum growing areas in the fall to harvest the grain. Before World War II, grain sorghums were used largely for feed, but since that time the financial returns of the farmer have been improved by the development of several new and improved varieties which show less tendency to lodge, are more resistant to damage by insect and disease, have higher yields and can be harvested and handled more economically. Milo is currently the leading type of sorghum grain grown in the United States. Plant breeders are continuing to develop newer and even better adapted varieties²⁷.

Processing and Uses of Grain Sorghum and its Products

Research concerning ways and means of diversifying the uses of sorghum grain and its products has been under way for some time, but, to make the results valuable, it was necessary to study methods for processing the grain. As with corn, wet and dry milling processes were developed.

Wet Milling. The sorghum wet milling process is similar to that for corn⁶⁴, although finer mesh screens and an increase in the pitch of the starch tables were necessary for efficient operation. Though corn grains are ten to fifteen times larger than sorghum grains, they have similar compositions (Table 14-15). Sorghum starch appears equivalent in quality to a large part of the general range of starches and much of the sorghum grain production is wet milled to give starch and starch products such as dextrose, and substitutes for "tapioca." Edible oil and gluten feeds are other products. Table 14-16 gives analytical data for the component parts of the sorghum kernel which were separated by hand after soaking the grain²⁰. Niacin is particularly abundant in the sorghum grain and appears to be an inherent varietal

TABLE 14-15. TYPICAL RESULTS OF LABORATORY WET MILLING OF CORN AND GRAIN SORGHUM^a

	Corn % (d.b.)	Grain sorghum % (d.b.)
Protein in grain.....	10.5	11.6
Starch in grain.....	70.5	72.0
Oil in grain.....	5.2	3.8
Yield of:		
Germ.....	7.2	4.3
Fiber.....	8.4	7.1
Gluten.....	11.5	11.4
Starch.....	62.8	65.5
Solubles.....	7.5	7.4
Oil in germ.....	52.6	43.6

^a Watson, Williams and Wakely⁶².

characteristic. Certain crosses have been grown with as high as 124 µg/g of niacin in the grain⁵⁹.

Dry Milling. Considerable effort has resulted in dry milling methods with great promise. Standard roller mills such as those used for processing wheat into flour were inadequate, but a procedure was developed which adequately met the imposed requirements. Continued effort has improved and refined the process. The percentages of various dry milled fractions and their important constituents are given in Figure 14-4.

The wax in the sorghum grain bran is a high melting wax similar in quality to that of carnauba wax, and should be usable in the formulation of numerous surface coatings. The germ fraction undergoes little tissue damage in the dry milling process and can be stored under ordinary conditions for long periods of time with only a slight tendency toward the development of rancidity. Sorghum grain oil is similar to corn oil and has many of the same uses.

The dry milling process yields grits very low in oil and fiber and thus suitable for production of flour of good quality which provides an excellent starting material for wet milling to starch. Grits can also be used in brew-

TABLE 14-16. SOME ANALYSES OF THE COMPONENT PARTS OF THE SORGHUM KERNEL^a

Product	Ash (%)	Protein (%)	Wax (%)	Oil (%)	Starch (%)	Niacin (µg/g)
Whole grain.....	1.65	12.3	0.32	3.6 ^b	73.8	45.3
Bran.....	2.02	6.7	—	4.9 ^b	34.6	44.0
Endosperm.....	0.37	12.3	—	0.6	82.5	43.7
Germ.....	10.36	18.9	—	28.1	13.4	80.7

^a Hubbard, Hall, and Earle²⁰.

^b Oil in bran and whole grain includes wax.

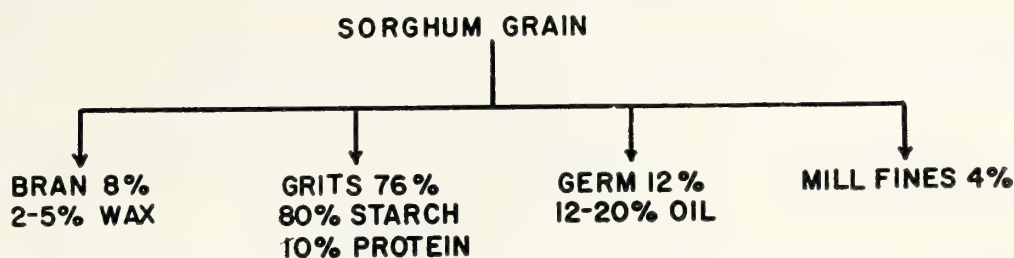


FIGURE 14-4. Fractions obtained from dry milling of sorghum grain.

ing grits, as corn grits and broken rice have been used. Sorghum grain flours have been converted to adhesives and sizings for various purposes. Kafir starches, whose pastes resemble those of root starches such as sweet potato starch, are excellent for food purposes, whereas the highly dispersible "waxy" starches are preferred for many industrial uses.

BUCKWHEAT

Production

Buckwheat, a native of China, is a shallow rooted, fast growing plant which thrives on poor, sour soils, where other cereals fail. Production in the United States, principally in New York, Pennsylvania, Michigan, Maine and Ohio, ranks third behind Russia and France. For grain production, buckwheat is usually seeded in late June or early July. Common buckwheat includes the Japanese and Silverhull varieties. The kernels are triangular in shape, dull gray or dark brown in color, with a thick fibrous pericarp.

Processing

About two-thirds of the annual buckwheat production is used on the farms where it is produced. Most of the grain that is processed for human food is milled into flour by a roller milling process similar to that for wheat flour production, but much shorter⁸. By-products are the middlings which have value as animal feed and the hulls which are usually burned.

Uses

Buckwheat flour is used almost exclusively for making griddle cakes and, in the United States, is sold more extensively in prepared pancake flour mixes than as pure buckwheat flour. Roasted cracked kernels and a coarse granular (granulation similar to farina) product are made from buckwheat groats and used as breakfast foods or porridge and in soups.

Table 14-17 gives the proximate composition of buckwheat and some of its milled products. Buckwheat middlings are rich in proteins, minerals and other nutritious substances and is valuable as a supplement feed for farm animals.

In recent years, the buckwheat plant has attracted attention as the best

TABLE 14-17. PROXIMATE COMPOSITION OF BUCKWHEAT AND ITS MILL PRODUCTS^a

Product	Moisture (%)	Protein (%)	Fat (%)	Fiber (%)	N-free extract (%)	Ash (%)
Whole grain.....	10.0	11.2	2.4	10.7	64.0	1.7
Flour, light.....	12.1	7.8	1.5	0.7	76.7	1.2
Flour, dark.....	11.7	15.0	2.8	1.1	67.7	1.7
Groats.....	10.6	11.2	2.4	0.6	73.7	1.5
Hulls.....	8.0	4.5	0.9	47.6	36.8	2.2
Middlings.....	10.7	27.2	7.0	11.4	39.1	4.6
Farina.....	12.0	3.7	0.4	0.4	83.0	0.5

^a Coe⁸.

source of rutin, a nontoxic glycoside capable of reducing capillary fragility in man⁶⁰. The rutin content reaches a maximum in green buckwheat leaves when only a few blossoms have formed and decreases rapidly when seeds appear. Since considerable losses of rutin occur with slow drying of the harvested plant, methods have been developed for rapid drying with hot air to a point where the brittle leaves and flowers can be easily stripped from the relatively moist and tough stems by mechanical action. Rutin can then be extracted from the leaf meal with hot water or dilute aqueous ethyl alcohol.

SPECIALTY CEREAL PRODUCTS

A growing proportion of the cereal grains reaches the consumer in a form bearing little or no resemblance to their original appearance or the appearance of their primary products such as flour or meal. Two major grocery products which involve cereal grains in this way are prepared breakfast cereals and prepared mixes.

Breakfast Cereals

Breakfast cereal preparations on the American market consist of two major types—those which require cooking before serving and those which are cooked and ready to serve¹⁷. The raw cereal breakfast foods include products made from the common cereals and mixtures of different cereal products such as corn meal, rolled oats, cracked wheat, and farina.

Ready-to-serve cereal breakfast foods may be classified further into those made from entire grains or their mill products and those made from fabricated cereal products. On the consumer market, both of these types assume various forms such as flaked, shredded, granular, puffed and toasted breakfast foods. Recent developments have allowed many of these to appear in a sugar-coated as well as plain form. Most of the preparations are covered to some degree by patent protection.

Roasted cereals have also been used for a long time as substitutes for coffee and certain preparations still enjoy a limited market in the United States.

Prepared Mixes

Prepared dry mixes have made tremendous strides in the American market since World War II. Cereal flours, particularly wheat flour, now appear on the grocers shelf in intimate mixtures with many other ingredients to form a variety of products. Table 14-18 shows some of the many combinations of ingredients which may appear in prepared mixes.

Large-scale manufacture of these mixes for consumer use presented many

TABLE 14-18. SOME INGREDIENTS USED IN PREPARED DRY MIXES

Ingredient	Angel food cake	Layer cake	Cookie	Pie crust	Hot roll	Ginger bread	Muffin	Frost- ing
Wheat flour.....	x	x	x	x	x	x	x	
Wheat starch.....			x					x
Oat flour.....								x
Corn meal.....							x	
Corn sugar.....					x		x	x
Corn syrup solids.....								x
Sugar.....	x	x	x		x	x	x	x
Shortenings.....		x	x	x	x	x	x	x
Emulsifiers.....		x		x				x
Cocoa.....		x						x
Chocolate liquor.....		x	x					
Chocolate chips.....			x					
Whole eggs ^a		x	x				x	
Egg white.....	x	x		x				x
Egg yolk ^a		x	x			x		
Non fat milk solids.....				x	x		x	x
Salt.....	x	x	x	x	x	x	x	x
Soda.....	x	x	x	x		x	x	
Cream of tartar.....	x			x				x
Monocalcium phosphate.....	x	x	x	x				
Sodium acid pyrophosphate.....		x	x			x	x	
Vegetable gums.....								x
Carboxy methyl cellulose.....								x
Gelatin.....								x
Yeast.....					x			
Spices.....		x				x		
Flavoring.....	x	x	x			x		x
Accepted colors.....						x		x

^a Optional. Some manufacturers require the addition of egg solids from shell eggs in the home.

problems which had to be overcome. The necessity for long shelf life, uniformity of product, and good over-all taste appeal has put stringent requirements on the quality of ingredients used. Carefully prepared formulas, ingredient specifications, manufacturing and testing procedures, and packaging requirements are essential for successful mixes. These developments have involved ingredient suppliers who must modify or control their materials to give the results desired, formulators who devise formulas and ingredient specifications and conduct shelf-life studies, engineers who must design equipment and establish procedures to handle new and unfamiliar materials and operations, and packaging experts who must establish specifications for appropriate packaging materials. The development of such materials as antioxidants, desugared egg solids, active dry yeast, new packaging materials, etc., is a credit to the efforts of academic and industrial research organizations without which prepared mixes could not have advanced so rapidly.

The greatest problem which has perplexed and is still the concern of mix manufacturers is that of incorporation of shortening. Considerable research has been done on fat modification to make the job easier and still give the best possible performance in the mix product, but the problem is a continuing one. Two symposia have appeared discussing this and some of the other ingredient problems involved in prepared mixes^{44, 45}.

Figure 14-5 shows a simplified schematic diagram of a single specialty mix line. Dry ingredients are weighed out from pallet storage and fed into the dust-hooded feed hopper by hand. An elevator carries the ingredients up to a sifter from where the materials flow by gravity to a batch mixer. Shortening is introduced by cutting in or spraying from a pressure pot. After appropriate mixing, the stock may be passed through an Entoliter or a high-speed mixer from where it goes to surge bins and packaging lines.

A modern automatic prepared mix plant involving a complex array of equipment is described by Slater⁵⁵. Here five groupings of ingredients—flour, sugar, premixed minor dry ingredients such as salt, powdered milk, cocoa powder, leavening, eggs, etc., shortening, and flavorings—are maneuvered automatically into the mix line by appropriate use of hoppers, feeders, and conveyors. For bakery use, the product is packed in 100-pound bags which are passed through a metal detector before release for shipment. Bulk handling of flour, sugar and shortening has facilitated automatic operation.

Prepared Mixes for the Armed Forces. Bulk mixes have been used by bakers or institutions, but, since World War II, the U. S. Armed Forces have recognized the usefulness of these labor-saving food products in military operations. The use of prepared bakery mixes offers several distinct and important advantages which apply to general use as well as to the

Armed Forces. First, logistical problems are greatly simplified with all ingredients, except water, in a single package. Second, the demand for highly skilled bakers is greatly reduced. Third, complex machinery and equipment are no longer needed. Fourth, many of the potential sources of error on the part of the baker are eliminated. Thus, the production of uniformly good bakery products is facilitated and assured. Finally, the use of prepared mixes accelerates the production of a large volume of baked products in a short span of time.

The design of a set of prepared mixes of satisfactory palatability and acceptability, suitable performance, and comparative nutritional adequacy was accomplished by intensive research and development. Preparation of mixes capable of meeting the requirement for storage at 100° F for 12 months was far more difficult. During storage at least two significant chemical changes take place in chemically leavened prepared mixes, namely, the leavening chemicals undergo premature reaction resulting in an under-

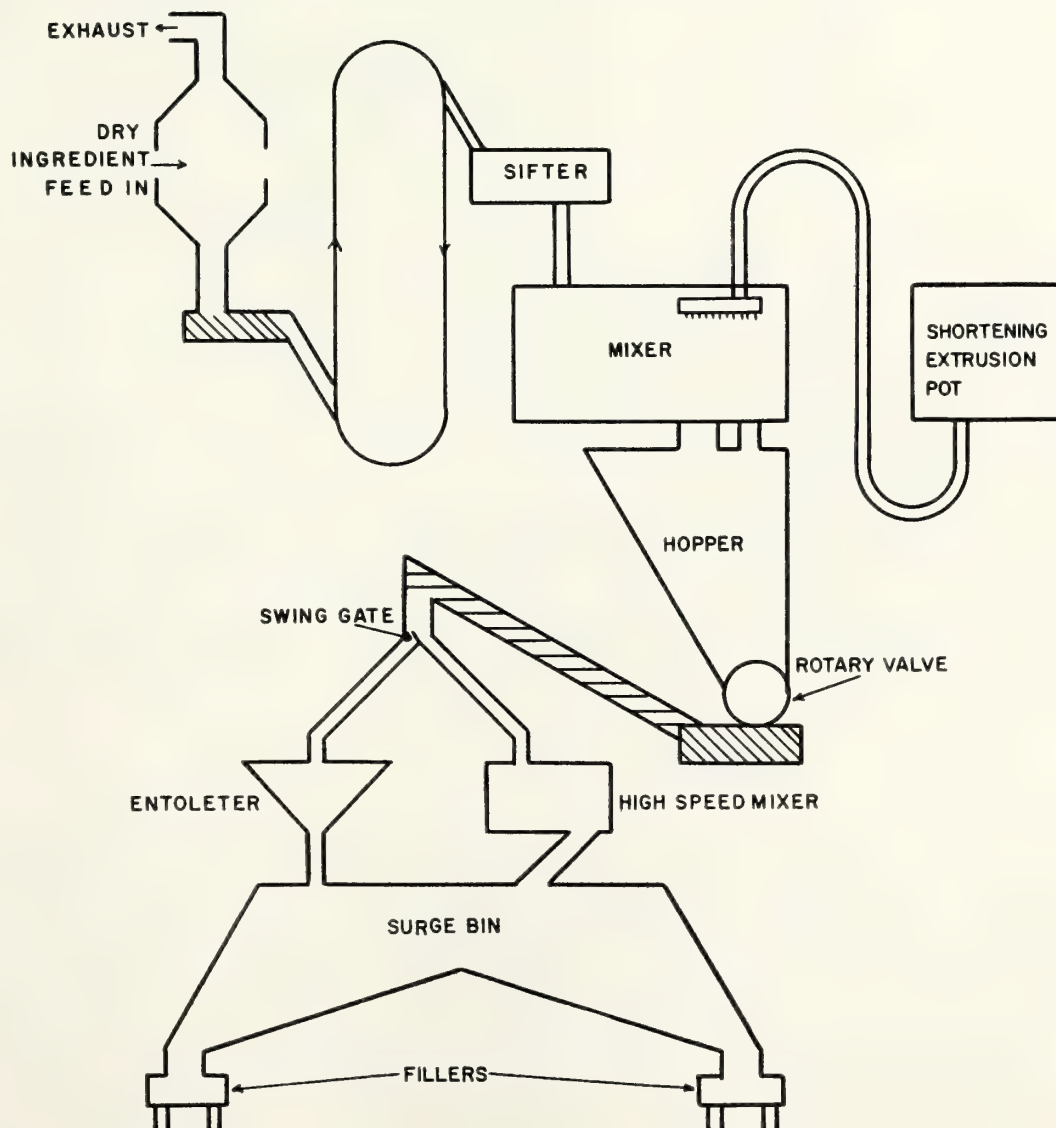


FIGURE 14-5. Schematic flow diagram of a single prepared mix production line.

leavened prepared mix, and the shortening combined in the prepared mix undergoes hydrolysis yielding substantial quantities of free fatty acids which give an offensive taste and drastically impair the baking performance. It has been demonstrated, however, that reduction of the normal moisture content of the prepared mix will inhibit and retard both of these adverse changes. Development studies have shown that if the wheat flour is dried from its normal 13 to 14 per cent moisture down to 6 or 7 per cent moisture the resulting prepared mix adequately packaged will satisfactorily withstand 12 months storage at 100°F without significant impairment of performance or acceptability.

Other Types of Mixes. In addition to dry mixes, prepared frozen and refrigerated doughs and batters are making their appearance on the American market. One of the most successful has been a biscuit dough packaged in a tube as individual precut biscuits ready to be placed in the oven. Prepared pancake batters in pressurized cans, pie doughs, and frozen cake batters have also appeared. It is obvious that such products increase immeasurably the storage problems encountered in the dry mixes. Even under refrigeration or in a frozen condition, shelf life has been very short, but there is considerable interest in this area as evidenced by recent tests comparing dry mixes, frozen batters, and frozen baked products^{26, 29, 42, 43}. Though the use of these products has been very limited, they may be as widely used in the future as prepared dry mixes are today.

NONFOOD USES OF CEREAL PRODUCTS

Cereals are primarily crops for food or feed and, in general, their most promising outlet for increased use is as human food. However, the vast amount of fundamental research on constituents of cereal grains has resulted in increasing demands on cereal products for nonfood industrial uses. A large amount of work in this area is going on which has not been publicized, but trends are developing and new products are appearing which suggest great activity.

Cereal Protein

There appear to be no great advances in nonfood uses of cereal fats, but considerable effort has been directed toward cereal proteins. A tremendous amount of work has been done on the zein from corn gluten⁴⁹. Commercially, zein is now being spun into fibers and, when blended with other fibers, is capable of being fabricated satisfactorily into clothing such as mens' suits.

Wheat gluten is the source material for several interesting materials. Gluten sulfate⁵⁰ and a phosphorylated derivative³⁵ have the unusual property of absorbing 100 to 300 times their weight of water to form firm, odor-

less, tasteless and nontoxic gels which have possibilities of serving as substitutes for scarce natural gums in pharmaceutical preparations.

Gliadin, extracted from wheat gluten, has been demonstrated to be an excellent additive at low concentrations (0.005 to 0.01 per cent) in preventing soil redeposition in textile cleaning operations using aqueous alkaline-built alkylarylsulfonate detergent solutions¹⁴. Strong, elastic, translucent films, useful for medicinal capsules, may be formed by heating dry undenatured gluten with glycerin and concentrated hydrochloric acid and then blending the mixture with wet gluten²⁴. Undenatured, powdered gluten may also be mixed with glycerol and treated under pressure to give a chewing-gum base²⁵. Gliadin can be incorporated in dry cells to inhibit corrosion of the zinc anode³⁶. Water-resistant, clear, flexible films of gliadin may be made by reacting the gliadin with ammonium sulfate and glycerin⁴¹. Adhesives may be prepared by reacting gluten with acrylonitrile and methyl acrylate in an alkaline solution⁹. Ether carboxylic acids are suitable plasticizers for materials composed basically of prolamines, such as gliadin and zein³⁷. These plasticized products are used for molded products, sizings, coatings, flexible films and adhesives.

Cereal Starches

As with protein, corn and wheat are the principal sources of cereal starches, with some recent interest in grain sorghum starch. The bulk of commercial cereal starches is used in the paper, food, and textile industries either in their native forms or as modified starches. The uses of cereal starches are well-known and are described adequately by Kerr²¹ or Radley⁴⁸.

Newer developments or trends have resulted from fundamental research concerning the components of starch, i.e., amylose and amylopectin. The amylose component consists of linear polymers which have the ability to orient in parallel fashion to form a gel. Gel formation is a characteristic of cereal starches and is important in many applications such as causing rigidity of the electrolyte medium in a dry cell. The branched-chain amylopectin does not gel readily, a property of importance in many sizing operations. At the present time separation of the two components from commercial starches at a reasonable cost has not been possible, but as a result of considerable work in plant genetics, hybrid varieties of corn (waxy maize) and sorghum (waxy sorghum) are now being grown commercially to yield starches which consist principally of amylopectin.

It is reported that the effective component of starch for sizing paper pulp in the beater is the branched polymer fraction, as measured by the increases in bursting strength over unsized sheets. Also, when used as an additive in oil well drilling muds the amylopectin is unquestionably the more desirable and effective constituent of starch. Other applications of the branched

polymer fraction are its uses as colloidal suspension agents and emulsification agents. The waxy starch products produce a smooth creamy texture in their pastes as contrasted with the stringy or "long" body of the non-cereal starches such as potato and tapioca or with the "short" body of the ordinary non-waxy cereal starches such as corn and wheat.

Research has shown that derivatives of the linear starch polymer, such as amylose triacetate, give films comparable in strength and flexibility to cellulose. Unmodified amylose films have been considered as potentially useful in the food and pharmaceutical fields.

Perhaps the greatest attainment in the starch industry in recent years has been the modification of cereal starches to give the properties and utility of root starches or waxy starches by means of low-substituted starch ethers, primarily the hydroxyethyl ethers prepared by reaction of ungelatinized starch granules with ethylene oxide in an aqueous alkali medium. These hydroxyethyl ethers are now being manufactured in several degrees of modification and reputed to offer new and substantial advantages for calender size, size press and tub size, coating and beater addition in the processing of paper. These ethers have been found promising also in the textile industry as a warp size due to their film strength and film flexibility.

High substituted ethers and esters soluble only in organic solvents have little industrial significance with the exception of allyl starch which is offered commercially and has promise as a protective and decorative coating for wood, glass, metal and other surfaces, and as a thermosetting adhesive suitable for preparation of laminated products. If the substituent contains a hydrophilic group such as in carboxymethyl starch ethers, the product remains soluble in water. Such products have been proposed for paper and textile sizing. Hydrophilic groups are also introduced into the starch granule by using dibasic acid anhydrides such as succinic and glutaric to lead to the formation of sodium half-esters of ungelatinized starch. When the starch esters of substituted dicarboxylic acids are treated with di-, tri-, or tetravalent metallic or alkaline earth metal ions, starch derivatives form which have a greater ease to flow in the dry state and which are also resistant to wetting by water. This type of starch product is of value to the graphic arts industry as a dry no-offset spray, in insecticide powders, and in textile sizing and finishing.

One of the most important types of starch derivatives is that formed with bi- or polyfunctional reagents, forming cross-links from one starch molecule to another. With slight treatment the gelatinization temperature is raised and a higher viscosity of the cooked paste is attained. This type of material has value as a textile printing gum due to its higher viscosity per unit of starch solids. As the degree of cross-linking is increased the starch granules become more resistant to gelatinization. A starch of this type has found interesting application as a dusting powder for surgeon's

gloves since it can be subjected to steam-sterilization without losing its dusting qualities. Some of the cross-linking reagents are formaldehyde and formaldehyde resins, dihalides and epoxyhalohydrins.

In addition to the starch modifications mentioned above, a large percentage of the total amount of starch used is treated by degradative processes to give starch products for particular applications. Another type of degraded starch, which is of tremendous importance in paper sizing, is the so-called chlorinated starch made by oxidation of the starch granules with sodium hypochlorite under alkaline conditions. In addition to their use in the paper industry the chlorinated starches are now expanding rapidly in laundry applications in the form of a cold-water dispersible starch in the dry state. Another large laundry starch development in recent years is that of the liquid laundry starch for home use. The starch property required here is primarily non-retrogradation and is attained with such products as starch ethers, waxy starch or chlorinated starch.

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15. DAIRY PRODUCTS*

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Production and Utilization of Milk

During the last decade milk production in the United States varied from 115 to 121 billion pounds per year. One hundred twenty-one billion pounds, a new high, was reached in 1953 and production in 1954 will probably exceed this figure. Milk is utilized (1) as fresh milk and cream, (2) in various processed forms such as cheese, ice cream, butter, and concentrated milk, and (3) in pharmaceutical, industrial, and livestock feed products. The quantities of dairy products manufactured from milk in 1952 are given in Table 15-1. Production data¹ tabulated² in Figure 15-1 show that approximately 35 per cent of the milk solids produced annually go to non-food use. Thirty-eight per cent is sold as fluid milk and cream; 32 per cent in various processed forms. Only 7.7 per cent of the total milk solids is now consumed as butter. This represents a drop in per capita consumption of butter from 18 pounds in 1925 to less than 9 pounds in 1952.

Intricate chemical and bacteriological problems arise in the production, processing, and distribution of milk products. Milk is a complex mixture of fat, protein, carbohydrate, and mineral constituents which is an excellent bacterial growth medium. Hence, care is required in food production while surpluses of various kinds are channeled to nonfood products. The excellent nutritional quality of milk, coupled with the high costs of producing it, have brought a gradual decrease in the quantities of milk diverted to industrial and feed use.

Dairy Industry Organization

The dairy industry is highly organized, each segment being represented by an association dedicated to its respective interests. The American Dairy Science Association is supported by scientists in production and manufacturing work in the universities, government, and industry. The National

* See also Chapters 10, 13 and 24.

TABLE 15-1. PRODUCTION OF DAIRY PRODUCTS IN THE UNITED STATES IN 1952*

Product	Production, million pounds
Milk	
On farm.....	115,197†
Total.....	115,597†
Butter, creamery.....	1,188
Ice cream (million gal).....	591.5
Sherbert (million gal).....	25.6
Cheese (excluding full skim American and cottage).....	1,170
Evaporated milk.....	2,840
Sweetened condensed milk (case and bulk).....	271
Nonfat dry milk (human food).....	863
Dry skim milk (animal feed).....	25
Dry buttermilk.....	47
Casein.....	7
Lactose.....	Not available
Dry whey.....	164
Full skim American cheese (thousand lb).....	.896
Cheese, cottage, creamed.....	440
Cheese, cottage, curd.....	376

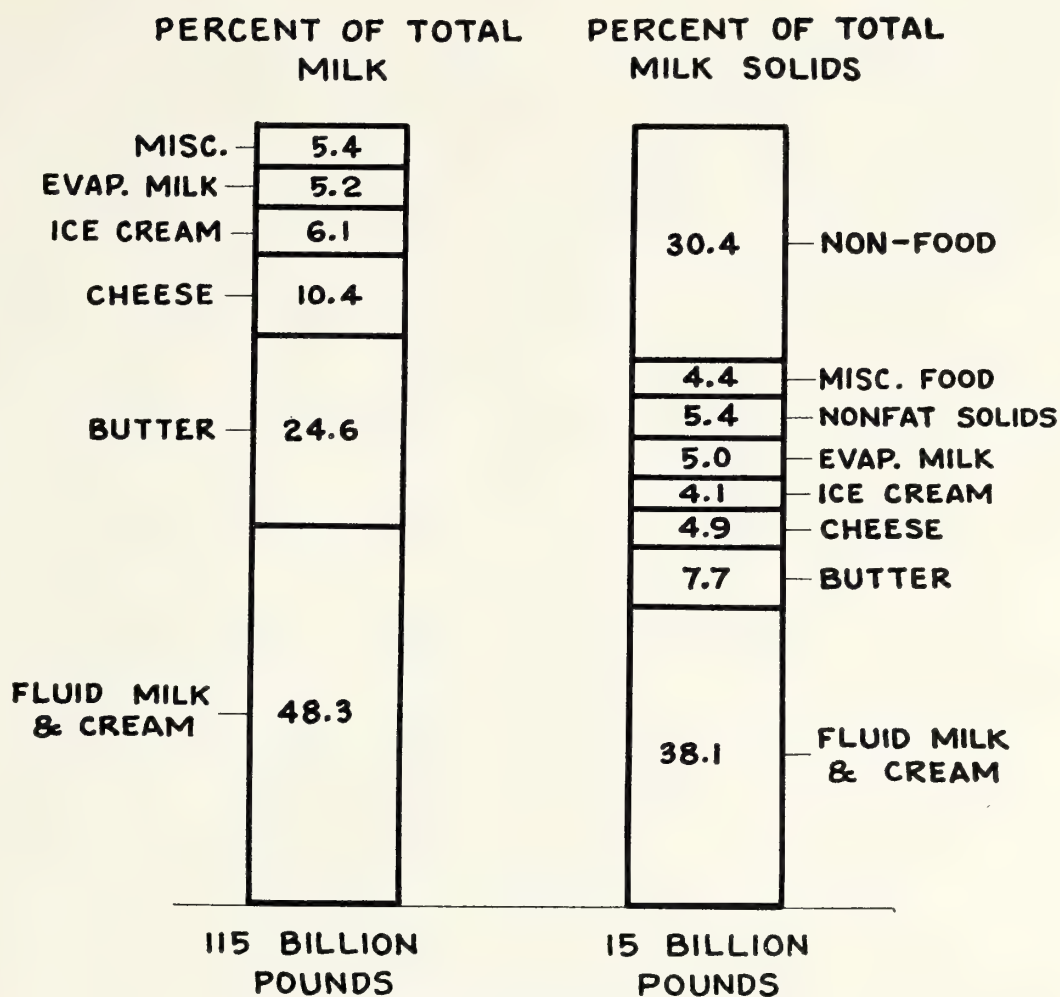
* All figures from Agr. Marketing Service Statistical Bulletin No. 136³³ except as noted.

† Agr. Marketing Service, "Farm Production Disposition and Income from Milk."³⁴

Dairy Council receives support from private industry; it sponsors research and promotional work to increase consumption of dairy products. The American Dairy Association, representing the dairy farmer, seeks to broaden the market for milk. Manufacturers of dairy products have formed the Milk Industry Foundation, American Butter Institute, National Cheese Institute, International Association of Ice Cream Manufacturers, Evaporated Milk Association, and American Dry Milk Institute. Representatives of these associations serve the national interests of their members as the Dairy Industry Committee. Dairy equipment manufacturers have formed the Dairy Industries Supply Association. Headquarters for most of these groups are in Washington, D. C., or Chicago.

Composition

The figures in Table 15-2, compiled by the United States Department of Agriculture³, represent some average values for cow's and goat's milk and for milk products made from cow's milk. Cow's milk decreases in fat content with breed approximately as follows: Jersey—5.3 per cent, Guernsey—4.9 per cent, Ayrshire—4.0 per cent, and Holstein—3.4 per cent. Inherited characteristics cause some differences among animals of the same breed. The fat content of milk is highest at the beginning and toward the end of

FIGURE 15-1.^{1,2}

lactation. Feed of the cow has a marked effect on the fat constants and the color and flavor of milk but not on the amount of fat present. The proportion of protein in the total solids of milk is relatively constant, being on the average approximately 26.5 per cent⁴.

Milk Fat. Milk fat or butter fat is a mixture of triglycerides of various fatty acids. It contains also a small amount of cholesterol (0.37 per cent), a substance characteristic of fats and oils of animal origin in contrast to those of plant origin which contain phytosterol, an isomer of cholesterol. The phospholipids, lecithin, cephalin, and sphingomyelin are present in milk within the range 0.0038 to 0.2889 per cent. These are fat-like substances containing phosphorus and nitrogen. They have emulsifying properties and are associated with the fat-globule surfaces, hence their tendency to concentrate in butter and buttermilk.

The fatty acids of milk fat and some of their physical constants are shown in Table 15-3. Often two or three different acids unite with glycerine to produce mixed triglycerides, thus making the composition of milk fat extremely complex. The glycerides contain relatively large amounts of the lower acids; namely, butyric, caproic, capric, caprylic, lauric, and myristic, and these are responsible for the characteristic flavor of milk fat.

TABLE 15-2. COMPOSITION OF 100-GRAM PORTIONS OF MILKS AND MILK PRODUCTS AS PURCHASED BY THE CONSUMER³

Product	Water	Food energy	Protein	Fat	Lactose	Ash	Calcium	Phosphorous	Iron	Vitamin A value	Thiamine	Riboflavin	Niacin	Ascorbic acid
	%	cal	g	g	g	g	mg	mg	mg	I.U.	mg	mg	mg	mg
Butter.....	15.5	716	0.6	81.	0.4	2.5	20	16	0.0	3,300	Trace	0.01	0.1	0
Buttermilk, cultured, made from skim milk.....	90.5	36	3.5	0.1	5.1	0.8	(118)	93	.1	Trace	0.04	.18	.1	1
Cheese														
Cheddar.....	37.	398	25.0	32.2	2.1	3.7	725	495	1.0	1,400	.02	.42	Trace	(0)
Cheddar, processed.....	40.	370	23.2	29.9	2.0	4.9	673	787	0.9	(1,300)	.02	.41	Trace	(0)
Cottage, from skim milk ^a	76.5	95	19.5	0.5	2.0	1.5	96	189	.3	(20)	.02	.31	(.1)	(0)
Cream cheese.....	51.	371	9.0	37.0	2.0	1.0	68	97	.2	(1,450)	(.01)	.22	.1	(0)
Cream														
Light, table or coffee.....	72.5	204	2.9	20.0	4.0	0.6	97	77	.1	830	.03	.14	.1	1
Heavy or whipping.....	59.	330	2.3	35.0	3.2	.5	78	61	.0	1,440	.02	.11	.1	1
Ice cream, plain.....	62.1	207	4.0	12.5	20.6	.8	123	99	.1	520	.04	.19	.1	1
Milk, cow														
Fluid, pasteurized and raw														
Whole.....	87.0	68	3.5	3.9	4.9	.7	118	93	.1	(160)	.04	.17	.1	1
Nonfat (skim).....	90.5	36	3.5	0.1	5.1	.8	123	97	.1	Trace	.04	.18	.1	1
Canned														
Evaporated, unsweetened.....	73.7	138	7.0	7.9	9.9	1.5	243	195	.2	400	.05	.36	.2	1
Condensed, sweetened.....	27.0	320	8.1	8.4	54.8 ^b	1.7	273	228	.2	(430)	.05	.39	.2	1
Dried														
Whole.....	3.5	492	25.8	26.7	38.0	6.0	949	728	.6	1,400	.30	1.46	.7	6
N.F.S. (skim).....	3.5	362	35.6	1.0	52.0	7.9	1,300	1,030	.6	(40)	.35	1.96	1.1	7
Malted, dry powder.....	2.6	407	14.6	8.5	70.7	3.6	287	379	2.1	1,020	.33	.54	—	(0)
Milk, goat, fluid.....	87.4	67	3.3	4.0	4.6	.7	129	106	.1	(160)	.04	.11	.3	1

^a Creamed cottage cheese contains approximately 4% fat.

^b Includes 44.2 grams sucrose.

Adulteration of milk fat with vegetable or various animal fats has tempted unscrupulous operators because milk fat is relatively high in cost and because its adulteration with 5 to 20 per cent of foreign fat is difficult to detect. Cheap milk-fat substitutes have been used in ice cream, condensed and evaporated milk, cheese, butter, cream, and other products.

Detection methods are usually based on some measure of the lower or volatile fatty acids present in a suspected sample, but the range of values of these acids in normal fats is so large that detection of minor adulterations is very difficult. A most valuable index for examination is the Reichert-Meissl number which in milk fat may vary from 23 to 33 while in most other fats it is less than 8. The Reichert-Meissl value is equivalent to the number of cubic centimeters of decinormal alkali needed to neutralize the volatile acids from 5 grams of fat. A test for the butyric-acid content of an unknown fat is a useful supplement to the Reichert-Meissl value for detecting adulteration. Determination of phytosterol which occurs in vegetable fat, although very difficult and time-consuming, may be used to detect as little as 5 per cent adulteration. Sesame oil has been added as a tracer to vegetable oil to be used with milk fat in parts of Europe and India. Tracer methods simplify detection of adulterants but require legal sanction and support.

The deterioration of milk fat is the cause of most off-flavor development in dairy products, the control of which requires technical understanding of the process involved. Holm⁵ has described four types of deterioration: (1) rancidity, caused by hydrolysis of the glycerides; (2) tallowiness due to oxidation of unsaturated fatty acids; (3) "oxidized" flavors probably caused by oxidation of phospholipids; and (4) fishiness, ascribed to both oxidation and hydrolysis.

Rancidity is brought about by fat-splitting enzymes (lipases) inherent in milk but which are inactivated by heat treatment. Pasteurization inhibits lipase action for as long as fluid milk is usually held, while sterilization of evaporated milk destroys the enzyme. Milk to be dried should be heated to 180°F for 30 minutes to assure destruction of lipase activity and prevent lipolytic action during storage of the dry product.

Oxidation of milk fat which results in tallowy flavor appears to occur as a result of the formation of hydroperoxides and their subsequent reaction with the fat. These reactions are greatly accelerated at high temperatures and acidities and by the presence of metal catalysts, especially copper. Oxidation is usually the primary cause for spoilage of dried whole milk, butter, and butter oil.

The origin of the so-called "oxidized" flavor is obscure, but it is not to be confused with the tallowy flavor produced when pure milk fat is oxidized. Origin of the oxidized flavor appears to be with the phospholipids and since

TABLE 15-3. FATTY ACIDS OF BUTTER FAT-QUANTITIES AND PHYSICAL CONSTANTS*

Acids	Grams per 100 grams fat	No. of C atoms	Mol. wt.	Melting pt. (°C)	Boiling point		Solubility in 100 cc			Volatility (steam)
					760 mm	Reduced pressures	Water	Alcohol	Ether	
Saturated								g	g	
Butyric	3.1	4	88	−7	163	—	Soluble	Soluble	Soluble	Volatile
Caproic	1.0	6	116	−8	202	—	0.882 15°	Soluble	Soluble	Volatile
Caprylic	1.2	8	144	16.5	236	—	(0.79, 15°)	Soluble	Soluble	Volatile
							(0.25, 100°)			
Capric	2.6	10	172	31.3	268	114 (15 mm)	0.10, 100°	Soluble	Soluble	Volatile
Lauric	2.2	12	200	43.6	>300	176 (15 mm)	Very soluble at 100°	134, 21°	Soluble	Appreciably volatile
Myristic	10.5	14	228	54	318	196.5 (15 mm)	Insoluble	44.9, 21°	Soluble	Very slightly volatile
Palmitic	26.3	16	256	63	—	215 (15 mm)	Insoluble	9.90, 20°	Soluble	Nonvolatile
								Very soluble (hot alcohol)		
Stearic	13.2	18	284	69.3	—	232 (15 mm)	Insoluble	2.0, 20°	Soluble	Nonvolatile
								Very soluble (hot alcohol)		
As arache- dic	1.2	20	312.3	77	328	—	Insoluble	0.45, 20° Soluble (hot alcohol)	Soluble	Nonvolatile

it generally develops under conditions favorable to oxidation, the term “oxidized” has been used to describe it. Oxidized flavor is not uncommon in fluid-milk products.

Fishy flavor is produced by hydrolysis of lecithin, a phospholipid of milk, with the formation of the causative agent, trimethylamine. It may develop in dried milk of high moisture content and in butter churned from acid cream.

Proteins. The proteins of milk fall into two groups; casein, precipitable by both acid and the enzyme rennin, and the whey proteins, which are heat denaturable. There is about 3 per cent casein in milk, the removal of which leaves a whey of approximately 1.0 per cent nitrogenous matter. Of this 0.6 per cent is heat-coagulable protein and 0.4 per cent is nonheat coagulable. The latter fraction is composed of protein-like fragments of a proteose or peptone nature plus other nitrogenous substances. Among these are small quantities of urea, creatin, creatinine, uric acid, and various forms of amino nitrogen. The distribution of amino acids in casein and the whey proteins is shown in Table 15-4. These values, prepared by the National

TABLE 15-4. AMINO ACID DISTRIBUTION IN THE PROTEINS OF COW'S MILK
Representative Values as Published by the National Research Council⁶

Amino acid	Grams amino acid per 100 grams of protein		
	Casein	I actalbumin	Beta-lactoglobulin
Dispensable			
Alanine.....	2.3	2.6	6.8
Aspartic acid.....	5.8	9.6	11.0
Cysteine.....			1.1
Cystine.....	0.34	3.1	4.0
Glutamic acid.....	21.7	15.2	19.8
Glycine.....	0.4	0	1.5
Proline.....	9.8	4.0	4.7
Serine.....	5.4	4.0	4.3
Tyrosine.....	5.96	4.0	3.7
Indispensable			
Arginine.....	3.77	3.4	2.9
Histidine.....	2.25	1.6	1.6
Isoleucine.....	6.1	5.1	6.8
Leucine.....	10.8	14.1	15.5
Lysine.....	6.8	7.3	11.3
Methionine.....	2.88	2.4	3.2
Phenylalanine.....	5.5	4.1	3.7
Threonine.....	4.35	5.0	5.3
Tryptophane.....	1.22	2.1	1.9
Valine.....	6.6	5.0	5.8

Research Council⁶, are the best approximations available, but they should be used subject to revision as new work is published.

Casein exists in milk as a calcium-caseinate calcium-phosphate complex; the percentage of these components being approximately 95.2 to 4.8 per cent. The dispersed casein particles appear to be spherical in shape and of various sizes. They are multiples of a unit particle approximately 66 millimicrons in diameter and 33 million molecular weight⁷. The size distribution of the casein micelles is not constant, but varies with aging, heating, concentrating, and other processing treatments. Processing alters the water-binding of casein and this in turn affects the apparent viscosity of products that contain casein. Changes in hydration have not been measured quantitatively although the casein particles of raw milk appear to consist of 1 volume of water-free protein and 3 volumes of solvate liquid⁷.

Casein is tasteless, odorless, and noncrystalline. It precipitates from milk (pH 6.6) at its isoelectric point, pH 4.7, by the addition of acid. The curd may be resuspended in water by stirring and the addition of alkali to pH 7. As the suspension is made more alkaline, the casein gradually dissolves and it is completely soluble at about pH 8.5. Casein gives the usual protein color reactions, biuret, Millon's, xanthoproteic, and Hopkins-Cole. Linderstrom-Lang⁸, Mellander⁹, Warner¹⁰, and Hipp and co-workers^{11, 12} have shown that the casein complex is not homogeneous, but that after it is removed from milk it is found to be composed of three fractions designated as α , β , and γ caseins. These caseins may be characterized by their distinct electrophoretic patterns. However, it is not known whether α , β , and γ caseins occur in fresh milk as such or as complexes of only one fraction, or whether they are formed as a result of fractionation procedures.

The whey or serum proteins have been partially resolved into three relatively homogeneous, crystallizable proteins: (1) β lactoglobulin (50 per cent of total serum protein), (2) an albumin resembling the albumin of bovine blood (5 per cent of the serum protein), and (3) β lactalbumin (12 per cent of the serum protein)¹³.

On heat denaturation the serum proteins show decreased solubility at pH 4.7 and in concentrated salt solutions. There is some variability in response toward heat treatment, but complete denaturation will occur during heating within the range of 60 to 80°C for periods of time up to 2 hours. There is practically no denaturation during normal pasteurization. Heat increases the activity of the sulfhydryl groups and the sulfhydryl titer can be employed as a measure of denaturation. The —SH groups are readily oxidized in liquid systems and consequently they appear to act as antioxidants to protect milk fat in dairy products. The fat of fluid milk, heated to produce a high —SH titer, shows increased resistance to oxidation and this carries through to the dried product which exhibits superior storage

stability if it is made from a high-heat milk. The high sterilization temperature to which evaporated milk is subjected, and the low oxygen content of the can, permanently protect this product from development of oxidized and tallowy flavors during storage.

Unheated milk is not a satisfactory ingredient for bread because it softens the dough and depresses loaf volume. This defect is overcome by heating the milk. Why heat improves the baking properties of milk is not clear, but good baking properties have long been associated with low whey protein nitrogen values. The deleterious effect on bread of insufficiently heated milk was thought to be caused by the reducing action of the —SH groups on gluten, but it is now known that β lactoglobulin which is the source of these groups does not depress loaf volume¹⁴. The responsible factor resides in the classical lactoglobulin fraction precipitated by half saturation with ammonium sulfate but it is as yet unidentified¹⁵.

Lactose. The sugar of milk, lactose, $C_{12}H_{22}O_{11}$, occurs in the milk of all mammals. It is mildly sweet with a final solubility in water of 10.6 per cent at 0°C, 17.8 per cent at 25°C, 29.8 per cent at 49°C, and 58.2 per cent at 89°C. Lactose, on hydrolysis by acid or the enzyme lactase, yields a mixture of equal parts of glucose and galactose. These are much more soluble than the original disaccharide. Lactose is a reducing sugar which is converted to lactobionic acid on mild oxidation. Two forms of lactose which differ in solubility and optical rotation are known. Alpha-lactose hydrate crystallizes at ordinary temperatures with one molecule of water but this is lost with the formation of the anhydride during heating to a temperature between 149 and 200.3°F. Beta lactose anhydride, more soluble than alpha, crystallizes from supersaturated lactose solutions at temperatures above 200.3°F. Solid beta hydrate has never been prepared. When either alpha or beta lactose is dissolved in water (68°F) the specific optical rotation of the solution gradually reaches +55.5°, that of the equilibrium mixture of 1.65 parts beta to 1 part alpha. The optical rotation of beta lactose is +35.0° and of alpha, +89.4°. The crystalline alpha hydrate is stable in dry air at room temperatures but both anhydride forms readily absorb moisture and change to alpha hydrate at ordinary temperatures. Alpha lactose crystallizes out in some dairy products and because of the hardness of its crystals and their slow and limited solubility, "sandy" products may result.

Lactose, when fermented by lactic bacteria, is the source of the lactic acid formed in sour milk and whey. Lactose is helpful in establishing a slightly acid reaction in the intestine which assists in calcium assimilation. Several references to the chemistry of lactose may be of interest^{16, 17, 18}.

Mineral Constituents. When milk is heated to a temperature high enough to volatilize the water and oxidize the organic constituents, the residue of

TABLE 15-5. COMPOSITION OF MILK ASH

	Range of values compiled by associates of Rogers ³⁷ %	
K ₂ O	17.6	to 28.8
CaO	19.9	to 28.7
Na ₂ O	2.6	to 11.1
MgO	1.0	to 5.0
Fe ₂ O ₃	0.05	to 0.40
P ₂ O ₅	21.6	to 29.3
Cl	12.2	to 16.4
SO ₃	2.55	to 4.1

inorganic oxides that remains is called the milk ash. Compositions of the ash are shown in Table 15-5. The calcium and phosphorus of the ash are of special interest because of their nutritional importance and because calcium phosphate is part of the casein particle, influencing its physicochemical behavior toward coagulation with rennin, acid, and heat.

Minor inorganic constituents are present in milk in small amounts. These include iron, copper, zinc, aluminum, manganese, iodine, cobalt, and others in trace quantities.

Miscellaneous Constituents. The hydrogen-ion concentration of milk increases slightly with age, after milking, as natural carbon dioxide escapes. Most samples of cow's milk vary within the range pH 6.5 to 6.7. The titratable acidity of milk is expressed as the number of milliliters of tenth normal sodium hydroxide required to neutralize 18 grams of sample with phenolphthalein as indicator. Titratable acidity expressed as per cent lactic acid may vary from 0.13 to 0.16 per cent.

Titratable acidity of fresh milk is an arbitrary measurement which is influenced by the protein and salt-buffer systems present in the particular sample. Citrates, phosphates, and carbonates, are the principal buffers in milk.

The quantities of some of the important vitamins in milk and its products are shown in Table 15-2. The vitamin D content of milk may vary from 30 I. U. per quart in summer to 6 in winter, depending upon feed and the sunlight that reaches the cow. Cow's milk is often fortified to contain up to 400 I. U. of vitamin D per quart. Vitamins A, D, and E (alpha-tocopherol) are fat soluble and stable at the heat treatments used in processing milk and milk products. The remaining vitamins are water soluble and of varying stability. Vitamins B₁, (thiamine) and C (ascorbic acid) are partially destroyed by heat while B₂ (riboflavin) and B₆ are heat stable, but are destroyed by light. However, pasteurized milk is a good source of all the milk vitamins except C.

Two types of enzymes in milk are important; those useful as an index of

heat treatment and those responsible for bad flavors. Phosphatase is destroyed by the heat treatments used to pasteurize milk, hence its inactivation is an indication of adequate pasteurization. Lipase catalyzes the hydrolysis of milk fat which produces rancid flavors. It must be inactivated by pasteurization or more severe heat treatment to safeguard the product against off-flavor development. Other enzymes found in milk include catalase, peroxidase, protease, diastase, amylase, oleinase, reductase, aldehyde, and lactase.

Fresh Milk and Cream

Almost half of the milk produced in the United States is sold as fresh or market milk and cream. The fluid-milk industry is strictly regulated as to public health safeguards and farmer pricing aspects. Many chemical, bacteriological, and economic problems are faced to insure a steady flow of wholesome milk from producer to consumer.

Market milk must be produced under strict sanitary conditions on the farm and in the plant. As a guide to this the U. S. Public Health Service has prepared a model sanitary code which is used on a voluntary basis by many state and local health authorities in prescribing regulations for the production and handling of market milk¹⁹.

Processing Market Milks. Pasteurization of milk is compulsory in most markets. It has been shown that pasteurization is the best method of destroying all pathogenic milk-borne bacteria and that the treatment does not appreciably lower the nutritive value of milk. Pasteurization is accomplished by heating the milk to 145° for 30 minutes or to 162° for 15 seconds. If the milk is to be homogenized, this should be done after it reaches 135°, but before pasteurization.

Homogenization reduces the larger fat globules of milk to about one-tenth of their original diameter and greatly increases the fat surface area that is capable of adsorbing protein. This treatment retards the rate of rise of the fat in milk and cream, eliminates cream-plug formation in storage, produces a smooth homogeneous body, a rich flavor, and it is said to improve digestibility. The milk fat should be liquid when it is homogenized, and a homogenization pressure of about 2,000 pounds per square inch should be used. Homogenization of cream tends to cause the fat to clump and this results in destabilization to heat, increases viscosity, and feathering in hot coffee. High cream acidity, high fat content, or homogenization at high pressure and low homogenization temperature, tend to increase fat clumping and feathering of cream. Coffee cream should be heated to 163°, then homogenized at 200 to 600 pounds pressure and finally held for 30 minutes before cooling. Whipping cream is not homogenized since to do so would prevent it from whipping.

The separation of cream is discussed under "Butter."

Market-milk plants produce special perishable milk products manufactured from fresh milk and cream. These include skim milk with or without vitamin supplementation, chocolate-flavored milk drinks made by the addition of sugar and cocoa to whole milk or skim milk, and cultured buttermilk or cultured cream prepared from skim milk or cream by growth therein of a lactic-acid producing culture. Cottage cheese is prepared from skim milk often with the addition of cream to the finished curd. Many fluid milk plants produce and market two or three dozen different kinds of milks, creams, or specialties. A complete discussion of this subject is presented by Sommer²⁰ and Roadhouse and Henderson²¹.

Preserved Fluid Milks

Methods of Preservation. Fluid forms of milk may be preserved by refrigeration, sugar, heat, acid, or salt. The first three methods have been used extensively. The addition of acid to produce pH 4.7 or salt to a concentration of 15 per cent are required to retard bacterial growth in liquid milks and these agents unduly alter the products. Plain and concentrated milks preserved by refrigeration or freezing, sweetened condensed milks preserved by sugar, and sterilized milks preserved by heat are of commercial importance.

A tabulation of the manufacturing processes and the storage requirements of some of these milks are given in Table 15-6. A full discussion of the concentrated milk industry is given by Hunziker²².

Preserved fluid milks are made by the careful use of heating and concentrating operations and, in the case of sweetened products, by the addition of sugar. Milk is always heated before it is concentrated or homogenized. The preheating or forewarming treatment affects its stability and viscosity after concentration. Milks that are to be concentrated for use in bakery goods or for sterilization must be heated almost to boiling before concentration. Sweetened condensed milk will thicken rapidly during storage if it receives excessive forewarming treatment, but 180°F for 15 minutes is needed to destroy yeast and bacteria.

Manufacture of Preserved Milks. Plain and superheated condensed whole or skim milk are sold in bulk, usually in 10-gallon cans, for use in the manufacture of bakery goods, confections, ice cream, and other foods. The concentration of these usually varies from 26 to 38 per cent solids. Milk becomes too viscous to handle easily when it is concentrated to more than 42 per cent solids. Lactose crystallizes slowly from the cold product when its solids content exceeds about 35 per cent.

Sweetened condensed milk is made in the same way as plain condensed milk except that sugar is added during concentration. The milk must be

TABLE 15-6. PRESERVED FLUID MILKS—MANUFACTURE AND STORAGE

Kind of milk	Means of preservation	Preheat treatment		Total solids content after concentration	Treatment of concentrate	Viscosity	Storage conditions required to maintain acceptability	
		Temp.	Time				Temp.	Time
		°F	min	%		centipoises	°F	weeks
Plain condensed								
Skim.....	Refrigeration	160 ^a	20	30	Cool to 40°F	20	40	3
Whole.....	Refrigeration	160 ^a	20	35	Cool to 40°F	35	40	3
Superheated condensed.....	Refrigeration	160	20	30	Heat to 190°F until thickened; cool by vacuum	40,000	40	3
Sweetened condensed								
Skim.....	Sugar	180	15	72 ^b	Cool to 86°, stir 2 hours, to crystallize lactose, cool to 60°	8,000	60	52
Whole.....	Sugar	180	15	72 ^c	Same	13,000	60	52
Frozen, pasteurized.....	Freezing	None		No. conc. 13	Pasteurize and homogenize, cool, package, freeze at −20°	8	0	26
Frozen, concentrated.....	Freezing	145	15	35	Homogenize, pasteurize, cool, package in cartons, freeze at −20°	35	0	10
Evaporated.....	Sterilization	200	10	26	Homogenize, cool, standardize, stabilize with salts, can, sterilize at 240° for 16 minutes, cool	40	70	52
Sterilized, H.T.S.T. process.....	Sterilization	160	¼	No. conc. 13	Homogenize, sterilize continuously in tubular heater at 280°, 15 seconds, cool, aseptically can	8	70	26

^a 185° required for milk for bakery use.
^b 12.8 lb. sugar/100 lb. milk added before concentration.
^c 18 lbs. sugar/100 lb. milk added before concentration.

carefully cooled after concentration to cause the lactose to crystallize as small, preferably 10-micron, crystals. When the crystals exceed 15 or 20 microns in size, the milk is said to be sandy. Sweetened condensed milk is packed in 15-ounce cans or in 50-gallon wooden barrels which hold 615 pounds of product. The milk must be held in cool storage to retard thickening, a reaction which proceeds logarithmically with increases in storage temperature and arithmetically with increases in storage time²³.

Frozen plain or concentrated milk is used because it can be made, held, and thawed to produce a milk of fresh flavor. However, its storage life is limited because the casein gradually becomes insoluble. It has been observed that this change is preceded by crystallization of the lactose in the frozen product²⁴.

The sterilized milk of commerce is known as evaporated milk. Except for a gradual separation of fat and a milk flavor change in storage, it is unusually stable for a fluid product. By processes recently developed, milk can be heated in a few seconds to 280°F, held at this temperature 15 seconds, cooled and aseptically canned to produce a product tasting almost as good as pasteurized milk. Extensive commercial use of this process has been retarded because a gradual thickening and insolubilization of the casein and an off-flavor develops. These may become noticeable after a few weeks of storage at room temperature.

Dried Milk Products

Milk products are dried to reduce volume, to preserve them, and to prepare them in a form useful for introduction into concentrated or dried foods. However, reduction to the dry state creates problems concerned with solubility, rehydration, and keeping quality. After a short period of storage, dried milks on reconstitution usually do not show the fine flavor characteristics of the fresh product.

Drying Processes. Milk may be dried by either of three types of processes: shelf or tunnel drying, including freeze drying; roller; drum or film drying; and spray drying. Hunziker²² has discussed various phases of these processes. Fluid milk products are almost always concentrated under vacuum to 20 to 40 per cent solids before they are dried. Vacuum evaporation is efficient and produces no high-temperature heating effects in the milk. Milks to be dried are heated before concentration and again before drying. If the powder is for general food use, a preheating treatment of the milk at 160° is used. When the dried product is to be used in baking or when dried whole milk is prepared, the milk is preheated to 185°.

Freeze drying may be accomplished by causing the ice crystals in a frozen product to sublime in a vacuum oven. Although it is expensive, freeze drying is useful where delicate flavors, culture organisms, or heat-sensitive

protein structures must be preserved. Freeze drying has not been adopted for the routine drying of milk products.

Roller drying is carried out by coating a single or double drum with the product to be dried, revolving the drums and scraping off the dried material. The drums are steam-heated and usually operate at atmospheric pressure. The interior drum temperature may vary between 250 and 340°F while the milk film itself must reach at least the boiling point to drive off the water. This relatively severe heat treatment with rapidly increasing solids contents insolubilizes the protein of milk and whey. The film is on the hot rolls for only 2 or 3 seconds but Wright²⁵ found that 50 per cent of the protein in an 88 per cent milk solids-12 per cent water mixture became insoluble in 0.4 seconds at 212°F. The solubility of the protein can be preserved by operating the rolls under vacuum, but the vacuum roll process is expensive and little used.

Spray-dried skim milk is made by atomizing skim milk in a stream of dry, heated air and then separating the dried particles from the moisture-laden air. The rapid removal of water from the particle keeps it cool even though it is momentarily suspended in air at 300°F, hence the excellent solubility of spray-dried powder.

Storage Changes. Most of the lactose in the spray-dried particle is amorphous and in this glass-like state it readily absorbs moisture. Moisture dilutes the lactose sirup and causes crystallization of lactose hydrate and this promotes caking. Paralleling these changes there is a gradual insolubilization of the milk proteins in the powder particle. Two approaches to the controlled crystallization of lactose in spray-dried products have been made¹⁷: (1) the milk or whey is concentrated, the lactose crystallized and the mixture dried; (2) spray powder is dispersed in a moist atmosphere to force lactose crystallization and residual moisture is removed by further drying. Most commercial powder is still made with the lactose in an amorphous state and it must be packed in moisture-tight containers during storage.

Dried-milk products that contain fat are packed in an atmosphere of nitrogen with an oxygen content in the container gas of 2 per cent. Only in this way can fat oxidation be practically retarded since the use of antioxidants has not been found very effective.

Skim milk, whey, and whole milk are the most important dried dairy products but others are made in lesser quantities. Most of these contain 2 to 4 per cent moisture except high-fat cream which may contain 1 per cent. Dried cream contains 50 to 72 per cent fat; ice cream mix about 27 per cent fat, 28 per cent solids-not-fat, and 40 per cent sugar; sweetened milk about 25 per cent sugar and 72 per cent milk solids including fat; malted milk 8 per cent fat and the remainder malt and milk solids; buttermilk 1 to 6 per

cent acidity as lactic acid, about 5 per cent fat, and the remainder nonfat milk solids.

Cheese

Most cheese is made from cow's milk, but the milk from goats, ewes, or other animals is used in countries where these animals are raised. The milk is first coagulated, the curd is stirred and heated to cause the whey to separate, then the curd is finally collected and pressed. Coagulation is brought about by addition of the enzyme rennin, derived from calves' stomachs, by bacterial development of acid in the milk or by a combination of both methods.

The action of rennin on casein is not well understood. It appears to cause a molecular rearrangement or a surface change which produces calcium paracaseinate from the calcium caseinate of fresh milk. The paracaseinate in the presence of calcium ions forms a clot. Clot formation is accelerated when factors such as the concentrations of calcium and hydrogen ions, rennin, nonfat milk solids, various salts, and the time or temperature of rennet action are increased²⁶.

Varieties of Cheese. More than 400 cheeses have been described by Sanders²⁷. Some 88 names have been used to describe these cheeses but there are only about 18 distinct types of natural cheese. Each type is made by a variation in the details of the standard processing steps: setting the milk, cutting, stirring, heating, draining, pressing and salting the curd, and curing the cheese. One typical cheese of each of the 18 types classified as to body characteristics follows:

- (1) Very hard grating cheese, low in moisture, (about 30 per cent), ripened by bacteria: Parmesan, Romano, Sapsago.
- (2) Hard cheese, moisture about 38 per cent,
 - (a) ripened without eyes by bacteria: Cheddar, Provolone, Edam and Gouda;
 - (b) ripened with eyes by bacteria: Swiss.
- (3) Semisoft cheese, moisture about 45 per cent,
 - (a) ripened by bacteria and surface microorganisms: Limburger, Trappist, and Hand;
 - (b) ripened principally by bacteria: Brick;
 - (c) ripened principally by blue mold in the interior: Roquefort.
- (4) Soft, moisture about 50 to 80 per cent,
 - (a) ripened: Camembert;
 - (b) unripened: Cottage, Cream, Neufchatel, and the whey cheeses, Mysost and Ricotta.

Manufacture of Cheddar Cheese. Cheddar or American Cheese comprises about 75 per cent of the cheese made in the United States. Its manu-

facture has been described in detail by Van Slyke and Price²⁸ and others. Cheddar cheese may be made from raw or pasteurized milk, the latter now generally being preferred. A bacterial starter is added to pasteurized milk cooled to 87°F and after about an hour, rennet and color are stirred into the milk. After 30 minutes when the curd is set, it is cut into 1/4-inch cubes. The curd is stirred continuously until the whey is drained during which time the mixture is heated to 100°F. Draining should be completed in 15 minutes when the curd is piled about 8 inches high on each side of the vat. When the cubes of curd stick together firmly, the mass is cheddared or matted, that is, it is cut into slabs 5 or 6 inches wide and turned frequently. The slabs are piled in layers, run through a curd mill, salted, put into hoops, and pressed for 12 to 24 hours. The cheese is then held at 55°F for 3 months or longer.

Control of the pH during cheese-making is very important since acidity affects the rate of escape of whey from the curd, the final moisture content of the curd, the nature of the bacteria that grow in both milk and curd, the rate of enzyme activity, the amount of calcium lost in the whey, and the flavor of the ripened cheese.

Butter

The process of making butter consists of concentrating the fat globules in fluid milk of 3 to 4 per cent fat to a plastic mass of 80 per cent fat. Cream of 30 to 40 per cent fat must be separated from the milk then neutralized if sour, pasteurized, ripened, chilled, and churned. Intricate problems in physical and colloid chemistry, as well as biochemistry, and in bacteriology are involved. In churning, some of the fat globules must be freed of their strongly adsorbed protein membranes and gathered together. The bacteriological factors that affect acidity and flavor must be carefully controlled.

Cream Preparation. The rate of separation of the fat globules in milk during cream production obeys Stokes law and is approximately proportional to the square of the globule radius. Mechanical separation, which is accomplished by increasing the force of gravity more than 1,000 times in a cream separator, reduces the fat content of the separated milk to less than 0.1 per cent and the size of the globules remaining in the skim milk to less than 1 micron. Although milk is usually separated warm on the farm, recently designed cold milk separators are gaining in favor for factory separation of milk.

Much farm cream arrives at the creamery in an acid condition and must be neutralized with calcium and/or magnesium hydroxides to about 0.15 per cent titratable acidity. Low acidity is necessary to avoid protein coagulation during pasteurization of the cream, to insure an exhaustive churning of the fat, and to produce a butter (about pH 6.8) of good keeping quality.

The cream is pasteurized at about 165°F for 30 minutes. A flash heat treatment followed by spraying the hot cream into a vacuum chamber to remove feed flavors is sometimes used.

Sweet cream may be ripened with a "starter" culture to produce mild acid and improved flavor. The active flavor constituents appear to be volatile fatty acids and diacetyl, an oxidation product of acetylmethylcarbinol. Sweet-cream butter from unripened cream is mild in flavor, but of better keeping quality than sour-cream butter.

Churning. Cream is churned at about 50°F but the exact temperature must be carefully selected because it governs the rapidity and exhaustiveness of churning, and the firmness of the butter. The temperature should be one at which there is at least partial solidification of the butterfat.

The mechanism of the churning process is not clear. One theory considers that when the cream breaks there is an inversion in phase from a fat-in-water emulsion (cream) to a water-in-fat emulsion (butter). The foam theory stated that the fat globules gather and pack in the foam but that the adsorbed membrane remains intact and the fat does not become the continuous phase. Holm²⁹ considers butter to be a mixture of fat globules, air bubbles, and water droplets each surrounded by a protective film and dispersed in a mass of free fat.

After churning, the buttermilk is drained away, salt is added, and the butter is worked or kneaded in the churn. It is then ready for packing and shipping. The processes of churning and working require about 1½ hours.

Continuous Buttermaking. Continuous buttermaking processes that avoid batch churning methods have been developed in recent years. At present, continuous processes are used to make only a small part of the world's butter. Four processes will be mentioned, the Fritz and Alfa processes developed in Europe, and the Sugar Creek-Cherry-Burrell and Creamery Package processes which originated in the United States.

The Fritz process produces butter by the continuous churning of 50 per cent cream under vigorous agitation in a horizontal churning cylinder. The butter contains 7 per cent air and shows a rather crumbly body. In the Alfa process, 80 per cent cream is cooled and agitated in a closed system to cause phase inversion. The butter contains both globular and free fat. The Sugar Creek-Cherry-Burrell method separates farm cream to 85 to 90 per per cent fat. This concentrate is adjusted as to composition, pasteurized, cooled, chilled, and worked. The Creamery Package procedure utilizes cream of 75 to 80 per cent fat and subjects it to high pressure (homogenization) to break the emulsion; the mixture is separated to 98 per cent oil which is made into butter by mixing it with 78 per cent cream, adjusting the composition, and passing it through a chiller worker.

Detailed discussions of butter manufacture may be found in the texts by

Hunziker³⁰ and by Wilster³¹. King³² has reviewed processes for continuous butter manufacture.

Ice Cream

Ingredients for Ice Cream. Ice Cream is made from four types of ingredients: (1) dairy products, (2) sweetening agents, (3) stabilizing materials, and (4) flavoring and coloring substances. The products from each class of ingredient are selected on the basis of quality, availability, and cost. They are blended together to make the ice cream mix which is then frozen, packaged, and hardened.

The dairy products used in the mix must include a source of milk fat, such as cream, milk, butter, or a whole concentrated milk product. Plain or concentrated skim milks or buttermilks are a common source of nonfat-milk-solids. The sweetening agent may be entirely sucrose but often about 25 per cent of the sucrose is replaced by dextrose or corn sirup solids to improve the physical properties of the ice cream. Stabilizers, such as gelatin, sodium alginate, or a gum, retard the growth of large ice crystals and aid in production of a smooth ice cream. Emulsifiers include lecithin, mono and diglycerides of the fatty acids, sorbitan monostearate, and similar materials. Vanilla, chocolate, fruits, and nuts are popular flavoring materials. Fruits must be impregnated with sugar to prevent them from freezing solid at serving temperatures. The flavoring ingredients are added to the finished mix before or while it is being frozen.

Preparation of the Mix. The ice cream mix is prepared in a large vat or tank, pasteurized at 155°F for 30 minutes, or its equivalent at higher temperatures and shorter times. The hot mix is homogenized at about 2,500 pounds of pressure to prevent the fat from churning out during freezing, to improve the whipping properties of the mix, and to produce a smooth-bodied ice cream. The mix is cooled and aged for about 4 hours further to improve its whipping properties.

Freezing the Ice Cream. Half the water of the mix is frozen in the freezer and most of the remaining water is then frozen to ice in a hardening room. The cylindrical freezer is provided with blades which scrape the freezing mix from the refrigerated metal walls of the machine. The temperature of the refrigerant, brine, or ammonia, may range from 0 to -15°F while the semifrozen mix reaches a temperature of 21 to 25°F before it is discharged as a slush into containers for hardening. Freezers are designed to freeze the mix rapidly so that the crystal nuclei will be very small and suitable as a depository upon which the remaining water can freeze during hardening. Slow and insufficient freezing of water either in the freezer or the hardening room produces coarse ice cream. Air incorporated in the ice cream as minute bubbles together with small ice crystals, produces the smooth texture desired in a high quality product.

Packaging and Storage. The ice cream emerges from the freezer to enter the package in which it is sold. These packages are held at 0 to preferably -25°F in the factory hardening room from whence they are taken to the distributors' cabinets, which provide storage temperatures from 0 to 12°F . Defects may be present or may develop especially when storage temperatures are high or fluctuating. Oxidized, metallic, feed, sour, fermenting, unclean, and cooked flavors in ice cream are known. The texture may become sandy, coarse, icy, flaky, or buttery, and the body crumbly, soggy, pasty, weak, foamy, or curdled. Ice cream that is carefully prepared from quality ingredients, hardened, and distributed according to recognized practice usually will not show or develop undesirable characteristics.

Dairy By-products

The by-products that remain from the manufacture of cream, butter, and cheese are skim milk, buttermilk, and whey. These are used in the preparation of foods, feeds, and industrial products. The concentration or drying of skim milk, buttermilk, and whey is generally necessary for most food uses. These processes and the resultant dairy foods have been briefly discussed.

Animal Feeds. Dairy by-products have become an important constituent of animal feeds because of their high nutritional value. They may be incorporated in dry form into mixed feeds. Skim milk and buttermilk are used in this manner when economics permit. Whey is often concentrated to about 45 per cent solids, allowed to set and the resulting gel fed to chickens and swine. Recently it has been found that enzymatic hydrolysis of the lactose in whey to glucose and galactose increases the amount of whey which may be incorporated in animal feeds. The coagulated protein, removed from whey during processing, is often dried for feed.

Industrial Products. Casein and lactose are the basic constituents from which many industrial, biological, and pharmaceutical products are manufactured. Casein is used in adhesives, paper-coating, plastics, and paints, as sodium caseinate in foods, and it is hydrolyzed to produce flavoring agents and bacteriological media. Lactose is used in penicillin manufacture and is an important ingredient in pharmaceutical preparations. Lactose in crude form or in whey has been used for several industrial fermentations. Lactic acid, ethyl and *n*-butyl alcohol, vinegar, and acetone are some of these.

The casein produced in the United States is acid precipitated except for a small quantity of rennet-precipitated casein used for plastics. Skim milk at about 100°F is coagulated with acid, usually hydrochloric at pH 4.1 to 4.7, the whey is removed and the curd washed, dried, and ground. The yield is 2.5 to 2.19 pounds of dry casein per 100 pounds of skim milk.

Lactose is made by first heat coagulating and removing the protein frac-

tions from cheese or casein whey. Hydrochloric acid, sulfuric acid, or lime are employed for pH adjustments; the optimum reaction depending upon the type of whey. The clarified whey is concentrated to 30 per cent solids, filtered and further concentrated to 60 per cent solids, dropped into crystallizers, held to permit crystallization, and centrifuged to remove the lactose crystals. The crude sugar may be refined by recrystallization from a decolorized clarified sirup.

A general discussion of dairy by-product manufacture is given in "By-products from Milk"¹⁷.

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16. VEGETABLE FATS AND OILS*

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Introduction

The fats make up one of the three classes of organic matter that are the main building materials of living organisms. Probably every live thing contains protein, carbohydrate, and fat, although in some the proportion of fat may be very small.

How fat is synthesized, and just what its function is in the living plant, do not appear to be known with any certainty, but its vital importance is evident from its presence in every cell, its concentration in reproductive organs such as pollen grains and seeds, and its intimate association with other substances known to influence life processes, such as the fat-soluble vitamins, sterols, and phospholipides.

To mankind, the vegetable fats are important first as food. They are a concentrated food material, having more than twice the net heat value of the same weight of carbohydrates or proteins. In addition, they serve as carriers of fat-soluble vitamins and they furnish the essential fatty acids without which the animal organism cannot thrive. Besides their direct nutritional value, they have the virtue of making other foods more appetizing. They are indispensable in practical cooking and baking, since many foods cannot be made fit to eat without fat.

The proportion of fat in natural foodstuffs varies greatly. In white potatoes the lipid content is about 0.5 per cent of the dry weight; in English walnuts it is about 69 per cent. Much of the fat consumed by man is taken with the natural foodstuffs without ever having been separated from the other plant material in which it occurs. The most important part of fat technology, therefore, consists in the isolation of fats and the refin-

* Condensation of "Vegetable Fats and Oils," ACS Monograph #123, Reinhold (1954). Reproduced with permission of E. W. Eckey, author and W. A. Hamor, Editor, ACS Monograph Series.

ing and processing needed to make them palatable and suited to various culinary requirements. The nonfood uses on the other hand, have long been important ones and are becoming relatively more so. Especially, the expanding use of fats as chemical raw materials for the synthesis of a great variety of improved and new products has been a feature of the chemical developments of recent years.

Fats Produced in Largest Tonnages

Of the thousands of species of oil-bearing plants, less than a score account for more than nine-tenths of the tonnage of vegetable fat used in the world. The oil crops produced in the greatest volume are shown in the following tabulation:

Oil crop	Millions of pounds of oil in the esti- mated average annual world production of the crop, 1934-1938	Principal producing localities
Coconuts	5,900	Indonesia, Philippines, India (including Burma), Ceylon, Malaya, Oceania.
Peanuts	5,200	India, China, French W. Africa, U.S.A., Nigeria.
Cottonseed	4,400	U.S.A., India, China, U.S.S.R., Brazil, Egypt.
Soybeans	4,000	China, Manchuria, U.S.A., Korea.
Rapeseed and Mustard seed	3,000	China, India, Europe, Japan.
Flaxseed (linseed)	2,600	Argentina, U.S.A., U.S.S.R., India, Europe.
Olive	1,900	Spain, Italy, Greece, Portugal, Syria, Tunisia, Algeria, Lebanon.
Palm (fruit)	1,600	Africa, Indonesia, Malaya.
Sesame	1,500	China, India, Burma, East Africa.
Sunflower	1,300	U.S.S.R., Romania, Bulgaria, Argentina.
Palm kernels	700	Africa, Indonesia.
Castor	446	Brazil, India, U.S.S.R.
Hempseed	290	U.S.S.R., China and Manchuria, Europe.
Tung	170	China, U.S.A.
Babassu	26	Brazil.

To this list may be added corn and cacao, which are not grown primarily as oil crops but which yield important tonnages of fat from the portion of the crop which is extracted.

The order in which the crops appear in this list may seem surprising, since some oils that are of relatively minor importance in the United States are high in the list. Peanuts, for example, are grown and used for oil production in much greater quantity in other parts of the world than in the

United States. An estimate of the quantity of vegetable fats and oils actually produced as such is given in Table 16-1.

In volume of world trade, the list would fall into a different order. Coconuts would still head the list, because a large proportion of the total production of coconut oil is exported from the countries where it originates, either as oil or in the form of copra. Peanuts would stay in second place, but from there on the order would be quite different. Only a small proportion of the huge cottonseed crop is exported from the countries where it originates. India's rapeseed oil and mustard seed oil are consumed mostly within the country. The same is true of sesame in Burma and sunflower in the U.S.S.R. On the other hand, India's flaxseed crop goes largely to more industrialized countries where linseed oil is in demand by the drying oil industries. Palm oil and palm kernels rank high in world trade, being produced largely for export.

The vegetable fats currently most important in the United States from the standpoint of tonnage consumed, are listed in Table 16-2. The values given in the table do not stay the same from year to year. Besides the changes in total consumption caused by changes in population and economic conditions, there have been remarkable shifts in the usage of different oils and fats in past years, and undoubtedly other shifts are in store. These may be caused by various factors, and are made possible by the fact that the various vegetable fats are to a considerable extent competitive with each other and with the animal fats. A change in price of a given fat, relative to others which may be substituted for it, promptly affects its usage. Such relative price changes may be caused by temporary conditions such as the weather affecting a particular crop or a particular locality, or by longer range influences such as the development of new crops, the adaptation of crops to new localities, the development of new uses for particular oils, and the imposition of taxes, import duties and other governmental controls. Also, the usage of particular fats has at times been affected by direct prohibitions imposed by government.

Remarkable changes have taken place within the memory of men now living. The cottonseed crushing industry was an infant industry in the United States at the time of the Civil War. Soon afterward, it expanded rapidly and by 1910 it had reached nearly its present capacity. Domestic production of soybean oil in the United States in 1930 was about 35 million pounds, about where cottonseed oil production was in 1875. In 20 years, the increase in the growing and crushing of soybeans was so amazingly great that soybean oil now ranks first in tonnage among the vegetable oils produced and consumed in this country.

The data of Table 16-3 provide another illustration showing how rapidly things can change. In three decades in the United States, margarine changed

TABLE 16-1. ESTIMATED WORLD PRODUCTION OF FATS AND OILS^a
(In millions of pounds)

Commodity	Total in fat or oil equivalent				
	Average 1935-39	1948	1949	1950	1951 ^d
Edible vegetable oils ^b					
Cottonseed.....	3,440	3,000	3,244	3,000	3,640
Peanut.....	3,320	3,750	3,860	3,880	3,930
Soybean.....	2,710	3,294	3,030	3,900	3,820
Sunflower.....	1,240	1,840	1,930	1,670	2,040
Olive.....	1,920	1,060	2,346	1,210	2,950
Sesame.....	1,440	1,440	1,550	1,550	1,530
Total.....	14,070	14,384	15,960	15,210	17,910
Palm oils ^c					
Coconut.....	4,260	2,860	3,840	3,980	4,570
Palm kernel.....	820	770	890	960	870
Palm.....	2,120	1,040	2,330	2,430	2,430
Babassu kernel.....	60	98	80	100	90
Total.....	7,260	4,768	7,140	7,470	7,960
Industrial oils ^b					
Linseed.....	2,290	2,548	2,440	2,292	2,150
Castor bean.....	400	460	440	460	450
Rapeseed.....	2,660	3,288	3,314	3,360	3,320
Oiticica.....	20	40	16	28	18
Tung.....	300	300	230	250	280
Perilla seed.....	130	10	10	10	12
Total.....	5,800	6,646	6,450	6,400	6,230
Animal fats					
Butter (fat).....	7,960	5,912	6,500	6,660	6,800
Lard.....	5,500	5,000	5,560	5,940	6,500
Tallow and greases.....	3,180	4,120	4,320	4,530	4,470
Total.....	16,640	15,032	16,380	17,130	17,770
Marine oils					
Whale.....	1,090	770	840	850	860
Sperm whale.....	60		140	110	180
Fish (incl. liver).....	1,000	520	620	750	790
Total.....	2,150	1,290	1,600	1,710	1,830
Estimated world total.....	45,920	42,120	47,530	47,920	51,700

from a product made mainly from animal fats to one in which the nut oils predominated, and then to one in which practically the only fats are cottonseed oil and soybean oil.

No doubt other changes just as remarkable will continue to occur to the end that human needs and desires may be satisfied with better and cheaper products. Perhaps some other crop will duplicate the record of the soybean crop. Among the oil crops that are candidates for increased cultivation in this country are sunflower, safflower, sesame, and castor. Improved varieties of these crops, adapted to machine planting, cultivation, and harvesting have been and are being developed. New and improved crops have been called our "green frontiers" which offer endless possibilities for pioneering.

In other parts of the world also, improvements in the production of oil crops may be expected. The remarkable yields of oil per acre that can be produced by the plantation cultivation of palms in the tropics (Table 16-4) excites the imagination. Such plantations have had notable success in Indonesia, Malaya, and Africa. Their acreage no doubt will increase in those areas, and possibly also in the Western Hemisphere, where the number of oil-yielding palms growing wild is immense.

The science and technology of utilizing the oil crops may be said to have developed to a very satisfactory state. In the recovery of oil from plant materials, its refining, processing and conversion to finished products, workable techniques are available and are widely applied. Many processes which originated more or less empirically have been modified and improved in recent years by the application of sound chemical engineering principles. The oil miller has a choice of improved hydraulic and screw presses or of several solvent extraction systems, and has the benefit of much knowledge concerning the proper handling and storage of his materials. The refiner may use batch or continuous processes, with improved equipment and methods to give good yields of refined oil. Much is known about how to avoid deterioration of the oil in handling and storage.

For conversion of oils to semisolid or solid fats, the hydrogenation process has great versatility. By its use and proper control, supplemented

^a From Foreign Agriculture Circular FFO 3-51, March 16, 1951; FFO 3-52, March 24, 1952, Office of Foreign Agriculture Relations, U. S. Department of Agriculture, Washington, D. C.

^b In the case of vegetable oilseeds, oil production has been estimated by assuming for each of the various crops that a certain proportion was crushed for oil. The years shown refer to the years in which the seed was produced and not necessarily when the oil was extracted.

^c Estimated on the basis of exports and the limited information available on production and consumption in the various producing areas.

^d Preliminary.

TABLE 16-2. ESTIMATED CONSUMPTION OF VEGETABLE OILS IN THE UNITED STATES FOR THE YEAR 1950

Oil	Total "apparent disappear- ance" millions of pounds	Used in manufacture of shortening	Used in manufac- ture of margarine	Used in manufac- ture of other edible products	Soap	Drying oil indus- tries	Other in- dustrial products	Refining loss
Soybean..	1,771	840	306	313	1	186	43	82
Cotton- seed....	1,602	549	429	467		0.03	9	148
Linseed...	595				0.03	566	14	15
Coconut..	547	0.3		119	257	3	136	32
Tall.....	286				13	35	205	32
Corn.....	242		0.2	224	0.03		2	17
Castor....	163				0.6	52	104	7
Peanut...	118	11	0.06	92			8	7
Tung.....	109					109		
Olive.....	77			76			0.2	
Palm.....	44				5		39	
Babassu..	39			3	36			0.8
Oiticica..	12					12		
Sesame...	9			9			0.2	

by other processing steps, improved shortenings have been developed, which keep fresh and retain desirable working properties. Fats for margarine manufacture and for many other uses are made by hydrogenation of fatty oils.

Fatty Acid Compositions of Various Fats

When a sample of any natural fat is saponified and acidulated, the fatty acids that are set free form a mixture. A few fats yield mixtures in which one kind of fatty acid constitutes 80 to 90 per cent of the total, but these are exceptional. Usually, two or three kinds of fatty acid are present in substantial percentages, together with minor proportions of others. The compositions of these fatty acid mixtures are interesting not only because they determine to a large degree the physical and chemical properties, and hence the field of practical usefulness, of the fats in which they occur, but also because they tend to fall into patterns which are characteristic of groups of fats which are closely related botanically. The relationship between composition and botanical origin which usually but not always is apparent is at least curious if not practically important.

In most of the vegetable fats, and in practically all of them that are used as food, the mixed fatty acids consist entirely of normal, straight-chain, unsubstituted acids having an even number of carbon atoms, in the

TABLE 16-3. FATS AND OILS USED IN THE MANUFACTURE OF MARGARINE IN THE UNITED STATES

Name of fat	Percentages of total fats and oils used						
	1916	1923	1932	1938	1943	1948	1951
Oleo oil.....	42.3	23.7	7.5	4.3	3.4	0.6	(a)
Oleostearine.....	1.3	2.4	2.2	1.0	0.7	0.4	(a)
Lard, neutral.....	20.5	15.0	5.6	0.5	2.1	0.5	1
Oleo stock.....	0.3	11.8	0.3	0.5	0.6	0.1	(a)
Other animal fats.....	1.3	0.8	.....	.....	0.2	.....	(a)
Total animal fats.....	65.7	53.7	15.6	6.3	7.0	1.6	1
Cottonseed oil.....	30.6	9.5	9.0	45.7	50.4	61.6	39
Soybean oil.....	.....	.....	.....	12.7	39.6	34.4	55
Peanut oil.....	3.3	3.5	1.5	1.2	0.9	1.5	(a)
Other domestic vegetable oils..	0.1	.....	.....	0.2	2.1	0.2	4
Total domestic vegetable oils	34.0	13.0	10.5	59.8	93.0	97.7	99
Coconut oil.....	0.3	33.3	73.7	28.7	.....	0.7	.....
Palm kernel oil.....	.....	.....	.....	1.5	.....	.....	.....
Palm oil.....	.....	.....	0.2	.....	.....	.....	.....
Other foreign oils.....	.....	.....	.....	3.7	.....	.....	.....
Total foreign oils.....	0.3	33.3	73.9	33.9	.....	0.7	.....
Total fats and oils (millions of lbs).....	163	197	167	312	500	735	847

^a 0.5 per cent or less.

range 6 to 24 per molecule. These may be saturated or unsaturated acids. The unsaturated ones commonly fall in a narrower range of chain lengths, from 14 to 22; those with eighteen carbon atoms per molecule occur much more frequently and in much greater total quantity than the others. Further, most of the unsaturated fatty acids are limited to those having one, two, or three double bonds, and usually those with more than one double bond have them in the isolated position, that is with a —CH₂— group interposed.

Corn Oil

Corn is the principal crop of the United States, with an annual production for the last decade averaging about 3,000 million bushels. The rest of the world produces annually a quantity ranging from a little more than half the production in the United States to almost an equal quantity. If the whole corn crop were milled for starch, the corn oil recovered annually in the United States, calculated at a ratio of about 1¾ lb per bushel,

TABLE 16-4. AVERAGE YIELD OF OIL PER ACRE, FROM SELECTED OIL CROPS

Crop	Producing area used for the calculation		Year	Yield of oil per acre (lbs)
	Locality	No. of acres planted		
Oil palm (in plantations)..	Netherlands E. Indies	167,774	1936	2503 ^a
Coconuts (in plantations).	Philippines	924,000	1932	730 ^b
Peanuts.....	North Carolina	270,000	1942	357
Soybeans.....	Illinois	3,470,000	1944	189

^a Includes the oil (200 lbs) from the palm kernels as well as the palm oil from the fruit.

^b Young plantations not in bearing were not included in the calculation. Yields from individual plantations as high as 1400 to 1600 lbs are not unusual.

TABLE 16-5. FATTY ACID COMPOSITIONS OF SELECTED OILS

Acid	Weight of individual acid, per cent of total fatty acids in the oil named									
	Coco-nut	Peanut	Cotton seed	Soy-bean	Rape-seed	Olive	Palm	Castor	Tung	Linseed
Caproic.....	0.5	.....	.....	} 0.2	.....	.....	.....	} 2.4	.....	.....
Caprylic.....	9.0	.....	.....		.....	.....	.....		.....	.....
Capric.....	6.8	.....	.....		.....	.....	.....		.....	.....
Lauric.....	46.4	.....	.....	} 0.1	.....	.....	.....		.....	.....
Myristic.....	18.0	.....	0.5		.....	1.2	1.5		.....	0.2
Palmitic.....	9.0	8.3	21.9	9.8	2.0	15.6	42.9		5.5	5.4
Stearic.....	1.0	3.1	1.9	2.4	.....	2.0	4.7		.....	3.5
Arachidic.....	.....	2.4	0.1	0.9	0.5	.....	.....		.....	0.6
Behenic.....	.....	3.1	.....	.....	1.5	.....	.....	} 0.6	.....	.....
Lignoceric.....	.....	1.1	.....	.....	1.0	.....	.....		.....	.....
Tetradecenoic.....	.....	.....	.....	0.1	.....	.....	.....	.....	.....	.....
Hexadecenoic.....	.....	.....	.....	0.4 ^a	.....	1.6	.....	.....	.....	.....
Oleic.....	7.6	56.0	30.7	28.9	15.0	64.6	39.8	7.4	4.0	19.0
Erucic.....	.....	.....	.....	.....	54.0	.....	.....	.....	.....	.....
Linoleic.....	1.6	26.0	44.9	50.7	16.0	15.0	11.3	3.1	8.5	24.0
Docosadienoic.....	.....	.....	.....	.....	2.5	.....	.....	.....	.....	.....
Linolenic.....	.....	.....	.....	6.5	7.0	.....	.....	.....	.....	47.0
α-Elleostearic.....	.....	.....	.....	.....	.....	.....	.....	.....	82.0	.....
Dihydroxy-stearic.....	.....	.....	.....	.....	.....	.....	.....	0.6	.....	.....
Ricinoleic.....	.....	.....	.....	.....	.....	.....	.....	87.0	.....	.....

^a Including hexadecadienoic.

would amount to about 5000 million pounds, a quantity greater than the production of cottonseed oil and soybean oil combined. Actually, the quantity milled is a small fraction of this. Most of the corn crop is fed on the farms and only about one-fifth is sold on the grain markets. The part that is sold is distributed, according to one estimate as follows: About 240 million bushels to meal, grits, hominy, etc.; 130 million bushels to starch, syrup and accompanying by-products; 56 million bushels to distillation and fermentation industries; 12 million bushels for the manufacture of breakfast cereals.

Corn oil is produced as a by-product of three of the corn-using industries. In the "wet-milling" industry, starch and its derivatives, corn syrup, dextrose, dextrin, etc., are the principal products; gluten feeds and corn oil are the main by-products. Corn products which consist mainly of the endosperm without separation of starch from gluten, such as corn meal, hominy, grits, pearl meal, etc., are made by "dry milling," which uses processes and machines resembling those used in the milling of wheat flour. In dry milling, corn oil may or may not be produced as a by-product, depending upon the size of the mill, the products made, and other factors. In any case, the quantity of oil produced per bushel of corn is less than half that which could be produced by wet milling. Distillers of industrial alcohol who use grain as a raw material, and some of the whiskey distillers, use dry milling processes to degerminate the corn before fermentation and recover the oil. Recovery of oil from the products after fermentation is not now practiced in this country.

The fat content of corn has not been changed significantly by the shift from open-pollinated varieties to the hybrid varieties of corn which now provide practically the whole of the commercial supply of corn for milling. No. 2 shelled corn of the dent varieties that make up the principal commercial supply averages 3.9 per cent fat, which corresponds with 4.6 per cent on a moisture-free basis. A recent study of 159 samples representing 17 farm-grown hybrid varieties showed them to average 4.7 per cent fat, on a moisture-free basis, with a maximum of 5.7 per cent and a minimum of 3.6 per cent. Individual varieties averaged as high as 5.2 per cent and as low as 3.9 per cent.

With the development of high-protein varieties of corn having greater feeding value and of high-oil varieties more valuable for milling, the possibility exists that the composition of the corn crop will change in the future. Strains of corn with as much as 12 per cent fat have been developed; crosses with the high-oil strain yielded samples with as much as 9.8 per cent. In two or three decades, possibly, the growing of corn with higher fat content will become so general that the bulk of the corn crop will go to extraction plants, as the soybean crop does now, before it is fed.

Other types of corn contain more fat than dent corn. Flint corn averages 4.9 per cent, popcorn, 5.5 per cent, and sweet corn, 8.7 per cent on a moisture-free basis.

The fat of the corn kernel is concentrated mainly in the germ (embryo). A study of open pollinated corn showed that the grains consist of 81.1 per cent endosperm, 11.5 per cent germ, and 7.4 per cent bran, which contained 1.15, 34.8, and 0.89 per cent of ether extractable material, respectively. In a study of eleven varieties of corn, mostly hybrids, averaging 4.8 per cent fat on the whole grain, the kernels were separated into four portions, endosperm, germ, bran, and tip cap portions. The kernels on the average, consisted of 81.9, 11.9, 5.3, and 0.8 per cent of these portions, respectively. The average oil contents of the respective fractions were 0.8, 34.5, 1.0, and 3.7 per cent. Of the oil in the whole kernels, about 84 per cent was in the germ and about 14 per cent was in the endosperm.

Wet Milling of Corn. This is done mostly in large plants capable of milling twenty carloads or more of corn a day. The grain is cleaned by a series of screens and air separators and then steeped in a water solution containing 0.2 per cent sulfur dioxide for about 48 hours at about 130°F. In addition to swelling and softening the grain, the steeping operation removes most of the water-soluble materials including sugars, some proteins and minerals. The solubles are recovered by concentrating the steep water, and are used either in the preparation of feeds by mixing with gluten and other by-products from later stages of the process, or as a nutrient in the manufacture of penicillin and streptomycin. An interesting by-product of steep water is phytin, which can be precipitated as calcium phytate by the addition of lime.

The steeped grain passes through degerminators, which are mills designed to break up the grain and loosen the germ without disintegrating it. The ground material drops to the germ separators, consisting of troughs in which the germ floats on a thin slurry of starch, 7–8° Bé, and overflows at one end of the trough. Any starch adhering to the germs is washed out through a series of reels, and the washed germ is passed through a dewaterer and then into a steam-heated rotary drier where it is dried to a moisture content of about 2.5 per cent. The dried germ contains about 50 per cent fat, a larger proportion than that found in germs separated by hand from kernels of unsteeped grain.

The general practice is to press the oil from the dried germs in screw presses. Some mills follow this with solvent extraction of the resulting cake in which case the screw presses are operated with more oil left in the cake, and at a correspondingly higher capacity, than when no solvent extraction is used. The recovery of oil in a modern mill using solvent extraction is said to amount to 1¾ lbs of oil per bushel, which would be about 3 lbs of oil per 100 lbs of grain.

Dry Milling of Corn. The procedures used for the dry milling of corn vary considerably depending upon the principal products produced and upon the size of the operation. A considerable quantity of corn, especially in the Southern states, is simply ground on burrstone mills to produce corn meal with no other processing except in some cases, a sifting to remove part of the bran. More refined corn products are produced with roller mills which use various arrangements of rolls, reels, aspirators, and sifters for the gradual reduction of the grain to smaller sized particles, and its separation into fractions rich in bran, germ, and endosperm, respectively. In such mills, the endosperm can be produced in the various particle sizes denoted by the terms hominy, grits, pearl meal, cream meal, etc., relatively free from bran and germ. In most of these mills, the fractions rich in germ are not processed to recover oil but are utilized in feeds. In other mills, especially those having a large capacity, the initial grinding of the grain, instead of being accomplished by the first set of rolls, is done in a mill called a degerminator, first introduced to the industry in 1900, which breaks up the grain and loosens the germ without much grinding action upon the germ itself. In both the straight roller mills and the mills using degerminators, the corn is first cleaned by a combination of screens and aspirators, then is mixed with warm water to bring it to a moisture content of 21 to 24 per cent. The grain is then held in a tempering bin for a time, usually about one to two hours, before going to the degerminator or rolls. From the degerminator, the broken grain passes through dryers, which remove part of the moisture, and through reels to make a rough separation of sizes, thence to aspirators, where the bran is removed, and then through a series of rolls, sifters, and aspirators. The germ being tougher than the endosperm tends to be flattened rather than ground by the rolls and can be scalped off by the sifters, i.e., they tend to be retained by the coarser sieves in the sifters. A perfect separation of germ from endosperm, and vice versa, is not possible by these methods. The germ produced in this way contains about 20 to 21 per cent fat. The usual method for recovering fat is to press the germ in screw presses which reduce the fat content of the cake to about 4 to 5 per cent. The average yield of oil is said to be about 0.6 lb of oil per bushel; yields as low as 0.4 lb and as high as 0.8 lb per bushel have been reported for different mills. Thus, only about one-third of the total oil is recovered in dry milling in those mills which are equipped for oil production.

Total production of corn oil in the United States was estimated to average 155 million pounds in 1937-1941 and 225 million pounds in 1942-1950. Crude corn oil usually contains less than 3 per cent of free fatty acid. Practically all of the oil produced is refined to produce edible oil. Conventional methods of alkali refining, bleaching, and deodorization are used, except that a chilling and filtering step is required in the processing to

remove a small quantity of wax, which if allowed to remain would separate gradually and make the oil cloudy. As in the case of other oils, the use of centrifuges is replacing kettle refining for the alkali refining step.

Although various industrial uses have been proposed for corn oil, nearly all of the refined oil is used as salad oil and cooking oil, either sold directly to consumers as such or indirectly in the form of factory-produced mayonnaise, salad dressings, and other products containing the oil. The low cloud point and melting point of corn oil and its relatively good keeping quality, favor its use for these purposes.

Composition of Corn Oil. The composition of the mixed fatty acids of corn oil as determined in several recent investigations is shown in Table 16-6. Linoleic acid and oleic acid are the principal fatty acids. Together, they make up 80 to 85 per cent of the total fatty acids of the oil. Saturated acids amount to 12 to 16 per cent; as in many other oils, the principal saturated acid is palmitic acid, associated with a considerably smaller quantity of stearic acid and a still smaller quantity of myristic acid. The presence of a minor quantity of hexadecenoic acid seems to be well established. The presence of acid more unsaturated than linoleic acid is in doubt. If such acid does exist in corn germ oil, it is present in only a very small proportion, hardly enough to have a significant effect upon the properties of the oil.

For comparison with oils from the corn germ, Table 16-6 includes the results of a study of the fatty acid composition of fats obtained from the starch and gluten fractions respectively of the corn grain. The acids of the fat from the gluten fraction have a composition almost the same as that of the acids of corn germ oil except that the proportion of acids more unsaturated than linoleic acid seems to be significantly higher. The acids from the starch fraction are composed of the same acids as those in the corn germ oil but the ratio of saturated acids to unsaturated acids is substantially higher, with palmitic acid constituting more than one-fourth of the total fatty acids.

The unsaponifiable portion of corn oil varies from less than 1 to almost 3 per cent. A large proportion of the unsaponifiable matter consists of sterols.

An important component of the unsaponifiable fraction is tocopherol, which keeps corn oil from oxidizing rapidly in spite of its large content of linoleic esters. Tocopherol in corn oil amounts to about 0.1 per cent of the weight of the oil and consists mainly of gamma-tocopherol which has relatively high antioxidant potency.

Characteristics of Corn Oil. Values for some of the characteristics of corn oil are given in Table 16-7. The oil has a low melting point, due to its low content of glycerides containing more than one solid fatty acid

TABLE 16-6. COMPOSITION OF CORN OIL FATTY ACIDS

Fraction of grain yielding the fat.	Germ ^a	Germ ^a	Germ ^a	Germ ^e	Germ ^g	Starch ⁱ	Gluten ^j
Fat content of fraction, %, dry basis.....					56.8	0.6	7.0
Iodine value of fat..	127.1		124.8	126.5	126	103	129
Composition of fatty acids, wt. % of total fatty acids	(b)	(c)	(d)	(f)	(h)	(h)	(h)
Myristic.....	0.1	1.7	0.5		0.2	0.7	0.6
Palmitic.....	8.1	11.0	9.7		9.9	26.3	11.4
Stearic.....	2.5	2.9	3.6		2.9	2.8	3.5
C ₂₀ -C ₂₂ sat'd. acids.....					0.2	1.5	0.2
Total saturated acids.....		15.6	13.8	15.8	13.2	31.3	15.7
Hexadecenoic....	1.2	1.6	0.2		0.5	0.8	0.3
Oleic.....	30.1	48.8	30.4	21.9	30.1	20.7	28.1
Linoleic.....	56.3	34.0	55.6	61.7	56.2	47.2	53.3
Linolenic.....				0.6	0.0	0.0	2.6
Acids above C ₁₈ ..	1.7						

^a Commercial corn oil, made by wet milling of corn.

^b By fractional distillation of methyl esters of the whole oil, and I.V., T.V. and Sap. V. of the individual fractions.

^c By fractional distillation of methyl esters of saturated and unsaturated acids after separation by Twitchell Method.

^d By a combination of fractional crystallization of fatty acids from acetone and fractional distillation of methyl esters of some of the fractions, and I.V., T.V. and Sap. V. of the various fractions.

^e Extracted with hexane.

^f Linolenic, linoleic and oleic acids by I.V. and spectrophotometric analysis. Saturated acids by difference.

^g Oil was extracted from germ obtained in commercial wet milling.

^h By fractional distillation of methyl esters and I.V., Sap. V., and spectrophotometric analysis of the fractions.

ⁱ Fat was extracted from "refinery mud" from corn sugar and syrup manufacture.

^j Fat extracted in lab, from dry gluten obtained in wet milling of corn.

per molecule. It is therefore a natural salad oil; that is, it does not require the removal of stearine, as does cottonseed oil, to put it into such condition that it will not become clouded by the separation of stearine when allowed to stand at ice-box temperatures. Mayonnaise made with corn oil withstands freezing without breaking of the emulsion, better than that made with most other salad oils.

TABLE 16-7. CORN OIL

	Usual range	Specimen
Fat, % of whole grain ^a	3.6-5.7	Germ ^e
Part yielding the fat.....	Germ	
Fat, % of part ^a	30-40 ^b	
Characteristics of fat		
Acid value.....	2-6 ^c	189 126.5 1.95 93.6 1.46725
Saponification value.....	187-196	
Iodine value.....	109-133	
Thiocyanogen value.....	71-77	
Hydroxyl value.....	8-12	
R-M value.....	Less than 0.5	
Polenske value.....	Less than 0.5	
Hehner value.....	92-96	
Unsaponifiable (%).....	0.8-2.9	
Fatty acid yield (%).....	93-95	
Refractive index, <i>n</i> _D , 40°C.....	1.464-1.468	14-20
Refractive index, <i>n</i> _D , 25°C.....	1.470-1.474	
Sp. gr., 25°/25°.....	0.916-0.921	
Melting point (°C).....	-18 to -10	
Titer (°C).....	14-20	
Composition of fatty acids, wt. % of total		
Volatile acids.....		15.8
Saturated acids.....	12-18	
Myristic.....	0.1-1.7	
Palmitic.....	8-12	
Stearic.....	2.5-4.5	
C ₂₀ -C ₂₂		
Unsaturated acids		
Hexadecenoic.....	0.2-1.6	
Oleic.....	19-49	
Linoleic.....	34-62	
Linolenic.....	0.0-2.9 ^d	0.6

^a Moisture-free basis.

^b On germs hand-separated from kernels. Germ fraction obtained in wet milling contains about 50% oil, and germ fraction obtained in dry milling, about 21% oil.

^c Poor quality grain in bad seasons may yield oil with higher acid value.

^d The existence of linolenic acid in corn oil seems to be in doubt. Linolenic acid det'd. by spectrophotometric methods possibly is attributable to absorption by oxidation products or other materials in the oil.

^e Extracted with hexane.

Coconut Oil.

Coconut oil and the other oils closely related to it, obtained from the kernels of various palm nuts, differ radically in physical characteristics and chemical composition from most other fats. The most readily noticeable physical characteristic, aside from the light color of the refined oil, is that coconut oil changes abruptly from a relatively hard and brittle solid to a clear oil within a temperature change of a few degrees, and that the transition occurs in the range of ordinary room temperatures. Butter fat, which is very soft on a warm day and hard and brittle when it is in the ice-box has this characteristic to some degree but not so strikingly as coconut oil. Butter fat melts completely at about 100°F and contains more than 40 per cent solid at 50°F. Coconut oil melts at 76°F and is more nearly completely solid than butter fat at 50°F. A few other fats, like cocoa butter and Borneo tallow, have an even more abrupt change in consistency with change in temperature, with the change taking place in a somewhat higher temperature range, but most fats are more heterogeneous and require a larger temperature interval to change from a hard solid to an oil.

These characteristics of coconut oil are due to the composition of its fatty acids and the way in which they are grouped in the triglycerides of the oil. About 90 per cent of the fatty acids of coconut oil are saturated acids and of these nearly half consist of lauric acid. Consequently, the oil contains a large percentage of glyceride molecules which contain two lauric acid radicals and which have nearly the same melting point. These characteristics of the oil make it easily adapted to uses for which the change in consistency over a narrow temperature range is desirable and make it less easily adaptable to uses for which this characteristic is undesirable. Thus coconut oil can be used to good advantage in margarine formulations when a butter-like consistency is wanted. It was extensively used in this country for this purpose for several years until its use was discouraged by considerations having nothing to do with the quality of the product (Table 16-3). The low degree of unsaturation of coconut oil makes it resistant to the development of rancidity caused by oxidation and allows it to be used in confections and fillings for baked goods that may stand for a relatively long time between manufacture and consumption. In some of these products, the quick melting characteristic of the coconut oil has the advantage of giving a pleasing, cooling sensation in the mouth when the products are eaten. This same characteristic on the other hand, is a drawback in the manufacture of plastic shortenings where brittleness and a large change in consistency with a small change in tem-

TABLE 16-8. COMPOSITION OF FATTY ACIDS OF COCONUT OIL

Sample	(a)	(b)		(c)			
Iodine value of oil . . .	7.8-8.2	8.7	8.0			9.3	6.0
Sap. value of oil	259.4-266.3	260.6				256.5	260.0
Comp'n. of fatty acids, wt. % of total fatty acids							
Saturated							
Caproic	0.3	.....	0.8	0.5	.....	Trace	
Caprylic	9.2	8.9	5.4	9.0	7.8	7.9	9.5
Capric	9.7	8.2	8.4	6.8	7.6	7.2	4.5
Lauric	44.3	52.1	45.4	46.4	44.9	48.0	51.0
Myristic	15.9	13.3	18.0	18.0	18.1	17.5	18.5
Palmitic	9.6	7.6	10.5	9.0	9.5	9.0	7.5
Stearic	3.2	2.1	2.3	1.0	2.4	2.1	3.0
Arachidic	Trace	Trace	0.4				
Unsaturated							
Hexadecenoic . . .		None	1.3				
Oleic	6.3	5.5	7.5	7.6	8.2	5.7	5.0
Linoleic	1.5	2.3	Trace	1.6	1.5	2.6	1.0

^a Oil from copra from South Sea Islands.
^b Oil from copra from Hainan Island, S. China.
^c Commercial oil from American refiner (California); probably from Philippine copra.

perature are undesirable. Some coconut oil is used in hydrogenated shortenings, mostly in formulations that contain not more than about 5 per cent coconut oil, and mainly for the reason that coconut oil is a good medium for the preparation of nickel catalyst.

Composition of the Fatty Acids of Coconut Oil. Several of the more recent estimates of the composition of coconut fatty acids made with the aid of fractional distillation of the esters or acids, are summarized in Table 16-8. About 90 to 94 per cent of the weight of the acids consists of saturated acids, which include all the even-numbered normal acids from caproic to stearic, with possibly a little arachidic acid.

The small proportion of unsaturated acid consists mainly of oleic acid, together with a little linoleic acid.

Characteristics of Coconut Oil. Table 16-9 gives some of the characteristics of coconut oil. These reflect the low degree of unsaturation of the oil and its relatively low molecular weight.

Refining Coconut Oil. Refining of coconut oil to make edible products is usually done by the conventional procedures of alkali refining, bleaching with earth or earth and carbon and deodorization with steam at low pressure. For some products, the steps of hydrogenation or graining and

TABLE 16-9. COCONUT OIL. FAT OF THE COCONUT, *Cocos nucifera* LINN

	Usual range	Specimen	British standard
Part yielding the fat.....	Copra, dried "meats," endosperm		
Fat, % of part, dry basis.....	65-72	65.7	
Characteristics of fat			
Acid value.....	1-10	1.1	14 max.
Saponification value.....	251-264	260.6	255 min.
Iodine value.....	7-10	8.7	7.0-9.5
Thiocyanogen value.....	6.1-7.0	6.7	
R-M value.....	6-8	6.6	
Polenske value.....	12-18	12.5	
Hehner value.....		90.7	
Unsaponifiable (%).....	0.15-0.6	0.38	0.8 max.
Refr. index, n_D , 40°C.....	1.448-1.450		1.4485-1.4492
Refr. index, n_D , 30°C.....		1.4536	
Sp. gr., 40°/25°.....	0.908-0.913	0.9203 ^a	
Melting point (°C).....	23-26	24.2	
Titer (°C).....	20-24		
Comp'n. of fatty acids, wt. % of total fatty acids			
Saturated acids			
Caproic.....	0-0.8		
Caprylic.....	5.5-9.5	8.9	
Capric.....	4.5-9.5	8.2	
Lauric.....	44-52	52.1	
Myristic.....	13-19	13.3	
Palmitic.....	7.5-10.5	7.6	
Stearic.....	1-3	2.1	
Arachidic.....	0-0.4	Trace	
Unsaturated acids			
Hexadecenoic.....	0-1.3		
Oleic.....	5-8	5.5	
Linoleic.....	1.5-2.5	2.3	

^a At 30°/4°.

pressing are included before the deodorization. The details of the alkali refining procedure differ considerably from those used with oils like cottonseed oil because of the more soluble nature of the coconut soaps. Also, the quantity of phospholipide and other material that must be removed besides free fatty acid is much smaller in crude coconut oil than it is in crude cottonseed oil and crude soybean oil. For these reasons, the quantity of lye used with coconut oil is only slightly in excess of that required to neutralize the free fatty acids. Procedures used differ somewhat among different refiners; water-washing and vacuum drying of the oil probably are more generally used than in the case of other oils.

TABLE 16-10. CHARACTERISTICS OF PEANUT OIL

	Usual range	AOCS	British standards	Specimens	
				Spanish	N.C. runner
Acid value.....	0.08-6		(a)	1.5	1.5
Saponification value.	188-195	188-195	188 min.		
Iodine value.....	84-102	84-100	82-99	94.3	93.1
Thiocyanogen value.	67-73	63		68.4	70.9
Hydroxyl value.....	2.5-9.5	8.6-9.6			
R-M value.....	0.2-1.0	Below 0.5			
Polenske value.....	0.2-0.7	Below 0.5			
Unsaponifiable (%)..	0.2-0.8	Below 1	0.8 max.	0.64	0.71
Refractive index, n _D , 25°C.....	1.466-1.470	1.467-1.470	1.468-1.472 ^b	1.4683	1.4681
Refractive index, n _D , 40°C.....	1.4605-1.4645				
Specific gravity, 15/15°C.....		0.917-0.921	0.917-0.919 ^c		
Specific gravity, 25/25°C.....	0.910-0.915	0.910-0.915			
Titer (°C).....	26-32	26-32			

^a To be agreed between purchaser and vendor. "The acidity of good commercial quality ground nut oil may range from hardly appreciable amounts up to 5%, calculated as oleic acid, according to season or district of origin."

^b Refractive index at 20°C.

^c Specific gravity at 15.5/15.5°C.

Peanut Oil

Peanuts are rich in oil and protein. A valuable bibliography which gives abstracts of the principal publications concerning the chemistry and technology of peanuts that have appeared in the years 1830-1939 has been published.¹

Properties of Peanut Oil. Some of the characteristics of peanut oil are given in Table 16-10.

Peanut oil is an excellent edible oil and the major part of the world production of this oil is used as food. It is well suited for use either unhydrogenated or hydrogenated. As a salad oil, peanut oil has a greater tendency to cloud when held at low temperatures than do most of the other oils commonly used as salad oils, but the crystals formed in the oil when this occurs are of a different type from those formed in other salad oils. Mayonnaise emulsions made with peanut oil have less tendency to break after being held at temperatures low enough to cause clouding of the oil than do those made with other salad oils.

Crude peanut oil contains a smaller proportion of phospholipides, pigments, and other minor constituents than do such oils as crude soybean and crude cottonseed oil. Cold pressed oil from good quality blanched nuts has such a small proportion of such constituents that it can be used as an edible oil without refining. Considerable quantities of such oil previously were produced in European mills. Hot pressed oils are relatively easy to refine to produce products with good flavor and keeping quality and having a light color. The oil hydrogenates easily. Large quantities are hydrogenated in India to produce vegetable ghees, and in other parts of the world for use as an ingredient in shortenings and margarine fats.

Composition of Peanut Oil. Peanut oil contains only a small proportion of nonglyceride constituents, so that in one sense its composition is relatively simple. Its fatty acid composition is complex, in that it includes saturated fatty acids covering a wide range of molecular weights.

The mixed fatty acids of peanut oil include about 7 per cent saturated acids with molecular weights higher than that of stearic acid, namely arachidic, behenic and lignoceric acids. Because of the difficulty of separating these acids from each other by crystallization methods, various publications of a few years ago questioned the identity of the arachidic acid of peanut oil with the normal C_{20} saturated acid. Some suggested that branched-chain acids or acids with an odd number of carbon atoms were present. This question has been settled by the fractional distillation of the methyl esters of peanut oil acids in precision fractionating columns under vacuum and proof that the fractions contain the normal C_{20} , C_{22} and C_{24} saturated acids.

The saturated acid present in the largest quantity in peanut oil is palmitic acid, as is the case of so many of the other vegetable oils. Stearic acid is present, and according to some of the more recent determinations, myristic acid in quantities up to 0.5 per cent (Table 16-11). According to one study, fractional percentages of caprylic and lauric acids, in addition to those already mentioned, can be isolated by precision fractionation of the methyl esters of peanut oil acids.

The unsaturated acids of peanut oil consist principally of oleic and linoleic acids. The oleic acid present has been shown to be the ordinary 9-octadecenoic acid. Linolenic acid appears to be entirely absent.

Soybean Oil

The soybean is one of the most interesting of the oil seeds, not only because soybean oil is one of the most important of the world's vegetable oils in terms of the quantity produced every year, but also because of its phenomenal history of rapidly expanding culture within the last two or three decades. In the western hemisphere, principally in the corn belt of the

TABLE 16-11. ESTIMATES OF COMPOSITION OF FATTY ACIDS OF PEANUT OIL

Source of peanuts	U.S.A. (b)	U.S.A. (c)	West Africa	West Africa	(d)	(e)	Argentina
Date of reports.....	1921	1921	1927	1934	1937	1945	1945
Iodine value of oil.....	94.8	90.1	.....	90.2	.....	93.6	96.4 ^f
Fatty acid composition, wt. % of mixed fatty acids							
Saturated.....	17.1	21.7	15.5	17.7	18.0	19.5	21.9
C ₁₄					0.4	0.5	0.4
C ₁₆	6.3	8.3	6.0	8.2	9.4	8.0	11.4
C ₁₈	4.9	6.3	3.0	3.4	3.1	4.4	2.8
C ₂₀ -C ₂₄ ^a	5.9	7.1	6.5	6.1	5.1	6.6	7.3
Unsaturated.....							
Hexadecenoic.....					0.9	1.7	2.4
Oleic.....	61.1	53.4	71.5	60.4	54.9	52.5	42.3
Linoleic.....	21.8	24.9	13.0	21.9	26.2	26.3	33.4

^a Arachidic, behenic and lignoceric acids are difficult to separate quantitatively. One estimate of their separate percentages is 2.4, 3.1 and 1.1%, respectively.

^b Oil pressed from Virginia peanuts.

^c Oil pressed from White Spanish peanuts, grown in the U.S.A.

^d Not stated. Probably oil from Indian peanuts.

^e Commercial oil supplied by British firm. Probably from Indian peanuts.

^f Oil had been slightly oxidized in storage. Original I.V. over 100.

United States, the growing of soybeans for oil milling has expanded from a quantity sufficient to produce about one million pounds of oil annually in the early 1920's to a quantity which currently yields nearly two billion pounds each year. The end of this expansion in the United States apparently is not yet in sight and a considerable expansion of soybean acreage in other countries of the western hemisphere in the next few years would not be surprising.

The factors which have produced this rapid change in the importance of the soybean as an oil seed crop are complex and their relative importance cannot be stated accurately. Probably among the most important is the fact that the soybean is an annual crop that is admirably suited to mechanized planting, cultivation, and harvesting. The expansion of soybean acreage has been simultaneous with a great expansion in the use of tractors, combines, and other tractor operated machinery. Other important factors are the fact that soybeans can be handled and stored without much difficulty, that mills have been erected for converting the beans to oil and meal, that markets for the oil and meal have developed in such a way as to provide good prices for soybeans, and that varieties

TABLE 16-12. SOYBEAN OIL CHARACTERISTICS

	Usual range	AOCS	British standards	Typical specimen	Unusual Specimens	
Acid value	0.3-3		3 max.	0.9	0.5	1.5
Saponification value	189-195	189-195	190 min.	193.5	193.0	191.1
Iodine value	117-141 ^a	120-141	129-143	131.6	139.4	102.9
Thiocyanogen value	77-85	79		81.3	85.1	78.0
Diene no.				0.7	1.6	0.2
Hydroxyl value..	4-8			5.8	4.9	5.3
R-M value	0.2-0.7	.				
Polenske value...	0.2-1					
Unsaponifiable (%)	0.5-1.6	Max. 1.5	1.2 max.	0.84	0.61	0.84
Volatile matter (%)			0.2 max.			
Refractive index, 25°C	1.471-1.475	1.470-1.476	1.473-1.477 ^b	1.4727	1.4740	1.4700
Specific gravity, 25/25°C	0.916-0.922	0.917-0.921	0.924-0.928 ^c	0.9195	0.9203	0.9159
Titer (°C)	22-27					
Color, 1" cell.			60Y, 6R Max.	35Y, 4R	70Y, 6.2R	70Y, 4.2R

^a Commercial oils mostly within the range 127-138.

^b At 20°C.

^c At 15.5/15.5°C.

of soybean and cultural methods have been developed to suit various climates and soils.⁵

Properties of Soybean Oil. Some of the properties of the oil are summarized in Table 16-12. Because of the large number of varieties of soybeans grown, and the diversity of soils and climate in which they can be cultivated successfully, the range of properties that may be exhibited by genuine samples of soybean oil is a wide one.

The iodine value of soybean oil varies with the variety and also varies in the same variety grown in different locations and in different years.

Uses of Soybean Oil. The principal uses of soybean oil are as food and as an ingredient in paints and other drying oil products. The quantity used for food far outweighs that for all other uses combined. In the United States, since 1946, soybean oil has amounted to about 50 per cent of the total tonnage of fats used in the manufacture of shortenings, and 35 to 40 per cent of the fats used for the manufacture of margarine. In 1950, these uses accounted for about 1,150 million pounds of soybean oil in the United States. Nearly all of the oil used for these purposes is hydrogenated.

Considerable quantities of soybean oil are used for other edible purposes also, including use of the unhydrogenated oil as a salad oil or cooking oil. Blends of soybean oil with olive oil are used extensively. The use

of the unhydrogenated oil for these purposes is limited to some extent by its tendency to develop a bad flavor or odor when stored in contact with air, or when heated to the temperatures used in deep-fat frying. This "reversion" is due mainly to the fact that the oil contains linolenic acid, and is much less of a problem in the hydrogenated fat.

Milling of Soybeans. Soybeans may be milled by any of the usual processes of hydraulic pressing, continuous screw pressing, or solvent extraction. The greater yield of oil per bushel of seed obtained with solvent extraction has been a sufficient incentive to cause the erection of a large number of solvent extraction mills in very recent years. In the crop year 1945-46, the percentages of the total quantity of soybeans crushed in the United States by hydraulic press, screw press, and solvent extraction, respectively, were 7.6, 64.2, and 28.2, with average oil yields per bushel being respectively for the three processes 8.46, 8.86, and 10.67 lbs. In the crop year 1949-50, the corresponding percentages had changed to 2.9, 41.2 and 55.9 and the corresponding yields per bushel were 8.38, 8.96, and 10.73. This trend has continued and ultimately nearly all of the soybeans crushed will be handled by solvent extraction.

Cottonseed Oil

Cottonseed oil is one of the most interesting of the vegetable oils, to American chemists especially, not only because it has been one of the most important of the edible oils used in North America for several generations but also because much of the technology in use in this hemisphere for the milling and processing of edible vegetable oils was developed to satisfy the needs of the cottonseed oil industry. The hydrogenation process, for example, was brought to the United States initially for the purpose of converting cottonseed oil to a hard fat which could be used to replace oleostearine in mixtures with unhydrogenated cottonseed oil used for making plastic compound.

World production of cottonseed oil amounted in 1951 to about 3600 million pounds; in 1950, about 3000; in 1949, about 3200. The average for these three years is a little less than the 1935-39 average of about 3400. Of the total world production of cottonseed, the portion produced in the United States normally amounts to between 35 and 45 per cent. In this country for some decades, practically all of the seed not needed for planting has been crushed for oil, but in some other countries a smaller proportion of the total production is utilized in this way. In India, for example, much of the seed produced has been fed directly to cattle or wasted. The expansion of the oil milling industry that has taken place in that part of the world in very recent years will no doubt cause most of the available seed to be milled for oil and meal, if it has not done so already.

The principal cotton producing areas outside of the United States are India, U.S.S.R., Brazil, China, and Egypt.

The fact that cottonseed is a by-product rather than primary product of the cotton plant makes any further large expansion of the cottonseed oil industry appear unlikely to occur. The market value of cottonseed is roughly one-sixth as great as the value of the cotton fiber and, therefore, the production of cottonseed is geared to the production of cotton fiber. Increasing world population and increasing standard of living may bring about gradual increase in cotton production, but broadly speaking, world production of cotton and of cottonseed appear to have reached a relatively stable level. This does not mean that rapid changes in local producing areas are unlikely to occur. The rapid expansion in the production of cotton and in the erection of cotton oil mills in western Texas, Arizona, and California in very recent years illustrate the changes that can occur in an old and apparently stable industry. New ideas and developments of course have potentialities for changing the general situation radically. Among such ideas that have been receiving attention are the development of new, large-scale uses for cotton fiber and the creation and improvement of varieties of cotton that yield more seed and less fiber than the varieties commonly grown.

A history of the development of the American vegetable shortening industry which ultimately provided the market for most of the oil produced by the cottonseed milling industry has been published. This includes an interesting history of the technology of the compound industry². For a chronology of events in the technology of cottonseed, see reference 3.

Some of the chemical and physical characteristics of cottonseed oil are summarized in Table 16-13.

Composition of Cottonseed Oil. Refined cottonseed oil consists mainly of the glycerides of linoleic, oleic, and palmitic acids. Other acids present in small proportions include myristic, stearic, arachidic, palmitoleic and possibly myristoleic acids. The variability of the composition is illustrated by the data of Table 16-14. These data are expressed in simplified terms with the saturated acids grouped together and with the monoethenoic acids calculated as though they consisted entirely of oleic acid.

Minor Components of Cottonseed Oil. The principal component of crude cottonseed oil, besides the fatty triglycerides and free fatty acid, is the phospholipide fraction. This ordinarily amounts to between 1 and 2 per cent of the weight of the crude oil. Its proportion is influenced considerably by the methods used in milling. The phospholipide fraction which can be precipitated from the oil by dilution with acetone or by the addition of moisture is not a single compound but a mixture, as is the case with the corresponding fraction from soybean oil, corn oil, and other

TABLE 16-13. USUAL CHARACTERISTICS OF COTTONSEED OIL

	Refined			Unrefined ^d	
	A.O.C.S.	British standards	Typical U.S. oils ^b	Range	Average
Acid value.....		0.4 max.	0.04-0.08	0.2-3.76	0.44
Saponification value.....	189-198	192 min.	192-195.6		
Iodine value.....	99-113	103-113	100-109.7	89.8-117	104.5
Thiocyanogen value.....	61-69		60.9-65.5	62.2-71.1	66.3
Hydroxyl value...	7.5-12.5		7.5-12.2		
R-M value.....	Below 1		0.25-0.75		
Polenske value....	Below 1		0.20-0.70		
Unsaponifiable (%).....	Below 1.5	1.2 max.	0.45-0.73	0.57-0.77	0.65
Refractive index, n _D , 25°C.....	1.468-1.472		1.4697-1.4698		
Refractive index, n _D , 20°C.....		1.472-1.473			
Specific gravity, 25/25°C.....	0.916-0.918		0.9161-0.9171		
Specific gravity, 15.5/15.5°C.....		0.921-0.924			
Titer (°C).....	30-37		31.2-36.9		
Color, Lovibond, red.....		3.5 ^a	4.0-10.7 ^c		
Color, Lovibond, yellow.....		35 ^a	35 ^c		
Cloud point (°F)...			28-42		
Pour point (°F)...			25-35		

^a Maximum value for common, edible, neutralized, washed oil, when measured through a 1-inch cell. Maximum value for deodorized oil, 7Y-0.7R.

^b Range found for 12 commercial crude oils, refined in laboratory; four from Arkansas, three from Georgia, and five from Texas.

^c 5¼ inch cell.

^d Oil extracted in laboratory with pentane from 48 different lots of seed, selected from 312 samples representing 8 varieties of cotton, grown at 13 experiment stations in 3 different years.

vegetable oils. An examination of phospholipides from cottonseed oil gave results suggesting that cottonseed phospholipides include compounds other than lecithin and cephalin, similar to those found in soybean phospholipides. The mixed fatty acids obtained from cottonseed phospholipides were found to consist principally of the same acids as those found in the mixed fatty acids from cottonseed oil, but the proportions of the individual acids differ significantly in the two cases.

TABLE 16-14. FATTY ACID COMPOSITION OF COTTONSEED OIL

Iodine value of oil.....	89.8-117.0 ^a	104.5 ^b	101.7	10.40	110.1
Thiocyanogen value of oil....	62.2-71.1	66.3	65.8	64.4	
Saturated glycerides					
By diff., thiocyanometric...	20.7-29.6	25.7	26.2	28.2	26.9
By diff., spectrophotometric			29.6	32.3	27.4
Modified Bertram method..			26.2	28.3	
Twitchell, lead salt-alcohol.				26.7	
Oleic glycerides				(c)	
Thiocyanometric method...	21.8-36.0	26.5	29.1	23.4	18.9
Spectrophotometric method			23.3	15.3	17.8
Linoleic glycerides					
Thiocyanometric method...	34.0-56.7	47.1	44.7	48.4	54.2
Spectrophotometric method			47.1	52.4	54.8

^a Range for 48 samples, from seed representing different varieties, localities and years.

^b Average for oils of Column 1.

^c Iso-oleic, 0.8%, by the Twitchell lead salt-alcohol method.

In addition to phospholipides, the settlings from crude cottonseed oil were found to contain carbohydrates, resins, inositol phosphates, phytosterol (sterol glucoside), and other materials.

Crude cottonseed oil contains a small proportion of gossypol and related pigment. The proportion varies depending upon the method of preparation of the crude oil. The range of gossypol pigment content has been given as follows: hydraulic pressed, 0.02 to 0.11 per cent; screw pressed, 0.25 to 0.47 per cent; hexane extracted, 0.05 to 0.42 per cent; cold pressed, 0.005 to 0.009 per cent; solvent extracted (acetone, methyl ethyl ketone, or ethyl ether), 1.25 to 1.43 per cent; refined, 0.01 per cent and less. Comparison of the results obtained with several samples, with and without a hydrolysis treatment to liberate free gossypol from bound gossypol, gave results indicating that practically all of the gossypol in crude cottonseed oil is in the free form.

The phospholipides and gossypol in crude oil are eliminated from the oil in the process of alkali refining, together with any impurities not soluble in oil, such as traces of meal and other substances that occasionally are present in the crude oil. Other pigments present in the crude oil also are mostly removed in the alkali refining. Some coloring matter, including carotenoid pigments, survives the alkali refining process but may be more or less completely destroyed or removed in subsequent processing. A considerable proportion of the unsaponifiable material of the crude oil remains in the refined oil. This fraction includes sterols, tocopherols, and hydrocarbons.

The mixed sterols of cottonseed oil have been found to consist pre-

dominantly of β -sitosterol. Ergosterol was found in a quantity estimated to be about 5 per cent of the total sterols. Mixed sterol glucosides were isolated from crude cottonseed oil in a quantity amounting to a little less than 0.01 per cent of the weight of the crude oil.

An important minor component of refined cottonseed oil is tocopherol, which not only has a large influence upon the keeping quality of the oil because of its antioxidant effect but also has nutritional importance as vitamin E. The quantity of tocopherol in cottonseed oil is approximately 0.1 per cent. The tocopherol in cottonseed oil is a mixture of alpha- and gamma-tocopherols, together with a small quantity of delta-tocopherol.

No reference to the question of the presence of allergens in products made from refined cottonseed oil would be necessary except for the fact that when clinical evidence was obtained some years ago showing that extracts of the cottonseed kernel contain an allergen of exceptional potency, some allergists mistakenly advised allergic persons that strict avoidance of foods containing refined cottonseed oil was necessary for them. Since some physicians still persist in advising certain patients to avoid salad oils and shortenings made from cottonseed oil, a quotation from an authority on the subject appears to be in order. "No justification remains for avoidance of foods containing edible cottonseed oil or hydrogenated cottonseed oil regardless of clinical sensitiveness to cottonseed allergen. Among the edible products of cottonseed, only the flour need be excluded from the diet to avoid the cottonseed allergen."

Production and Processing of Cottonseed Oil. Many of the methods used are similar to those used with other oil seeds, except for some modifications made to suit the peculiarities of cottonseed and cottonseed oil. The problems of cleaning the seed, for example, are somewhat different from those involved in the cleaning of smooth seeds, free from fuzz, such as soybeans. Also, the cottonseed must be delinted in machines operated on the principle of a cotton gin to remove the fuzz or linters which are valuable as a by-product and would interfere with the separation of kernels from hulls if not removed.

Adoption of solvent extraction methods has been slower in the cottonseed milling industry than in the milling of other oil seeds, especially soybeans. The bulk of the cottonseed crop in the United States until recently was still milled by hydraulic pressing methods but the situation is changing rapidly. In the late 30's, all of the United States production was in mills equipped with hydraulic presses or continuous screw presses. "The hydraulic press method standard for over 40 years was used almost exclusively. Expeller methods accounted for about 3 per cent of the total. Solvent extraction was not used." About the same situation existed up to 1946 but solvent extraction units for operation on cottonseed began to

be installed at about that time. Much work has been done on the extraction of cottonseed with solvent in very recent years and is still continuing. No doubt the proportion of cottonseed milled by solvent extraction, said to be not more than 5 per cent of total annual production in 1950, will continue to increase. Commercial installations include not only straight extraction types but also combined types in which the meats are pressed first in continuous screw presses and then extracted with solvent.

Practically all of the crude cottonseed oil produced in this country is refined for use in edible products. Of these, shortening is the principal one and the three classes of products, shortenings, cooking and salad oils, and margarine, account for more than 95 per cent of the refined cottonseed oil produced.

A comprehensive and authoritative discussion of cottonseed and its products has been prepared by the collaboration of a number of competent authorities⁴.

Olive Oil

Olive oil is one of the most important of the vegetable oils, not only in terms of the quantities produced and consumed but also because of the antiquity of its culture and the extent of its influence upon the arts of western civilization. The many references to olive trees, olives, and olive oil that occur in the Bible are an indication of how much this tree and its products meant to the people of the Mediterranean Basin in earlier times. In more prosaic terms, the continuing importance of the olive in this region can be shown by statistics of the production and consumption of olive oil. Of the total quantity of fats and oils consumed, olive oil is said to account for 84 per cent in Spain, 93 per cent in Greece, 54 per cent in Italy, 2.4 per cent in France, and about 0.5 per cent in the United States.

Total world production of olive oil in a typical year is about 2,000 million pounds. The only vegetable oils consistently produced in much greater quantities than olive oil are peanut, soybean, coconut, cottonseed, rapeseed, and linseed oils (Table 16-1). Most of the world supply of olive oil is produced and consumed in the countries of the Mediterranean Basin but some is produced in North and South America.

Methods of milling olives vary greatly. The method most commonly used is some form of crushing and pressing. Many small mills using hand-power and animal-power presses in which the pressure is applied by means of a screw are still in existence. The larger and more modern mills use hydraulic presses of various types. The usual process consists of a cleaning of the fruit by sieving and washing with water, grinding the fruit, a first pressing at moderate pressure, a second pressing at higher pressure, usually with an additional grinding of the press cake between the two

pressings, and finally an extraction of the residue with solvent. Some mills use three or more separate pressings but the trend appears to be toward the more simplified processes with only two pressings or even only one pressing followed by solvent extraction of the residue.

Numerous variations in procedure exist for each of the steps recited above. The washing of the fruit sometimes consists simply of the action of a small stream of water running through a screw conveyor which moves the fruit to the grinder or, in some mills, it is omitted entirely. Grinding of the fruit commonly is done in edge runner mills. For the first pressing, a light grinding which fails to crush the pits is used by some, while others grind the fruit thoroughly enough to crush the pits before the first pressing. Fluted rolls or other types of crushing machinery are used by some mills.

Various other methods for separating the oil from olives have been proposed. One system which is used to a considerable extent is the so-called Acapulco process, which involves rubbing the finely crushed olive pulp previously freed from pits against a fine screen which retains much of the pulp and allows most of the oil, together with some finely divided pulp, to pass through.

In the pressing of olives, a mixture of oil and aqueous juice is obtained. This mixture is separated as rapidly as possible by settling, or preferably by centrifuging, to avoid the hydrolytic action of the water which tends to be accelerated by the materials present in the aqueous juice. The separated oil usually is still turbid and contains dissolved moisture. It is clarified either by being allowed to settle for a long time or by filtration.

Oil from the first pressing constitutes the so-called virgin olive oil and usually is kept separate from the oil from subsequent pressings, since the oil from later pressings contains a larger proportion of free fatty acids and has a stronger flavor. Oil extracted with solvent from the pressed residues ordinarily contains too much free fatty acid, and is too highly contaminated with nonfatty substances, including pigments and materials having a strong odor and flavor, to be considered an edible product. Usually the pressed residues are not dried promptly enough to prevent the occurrence of extensive hydrolysis and other changes prior to the extraction. This oil is commonly referred to as olive foots or as sulfur olive oil. The term sulfur olive oil originated because the solvent commonly employed for extraction of the oil when the method first became widely used was carbon disulfide. At present, carbon disulfide has largely been replaced for this application by other solvents.

Refining. Good grades of olive oil receive no refining other than clarification obtained by settling or centrifuging and filtration, except that in some cases a winterizing process is used to remove stearine from oils which

contain a larger quantity of solid glycerides than is present in the average olive oil. Nevertheless, a large quantity of olive oil is refined with alkali and deodorized. This oil is from second or later pressings, or in many cases includes the first pressings from small mills not operated in such a way as to produce a good quality of virgin oil. The refined and deodorized oil is often mixed with raw oil in order to restore the olive oil flavor. Some countries have laws and regulations requiring the labeling of refined olive oil as such and prohibiting the mixing of refined oil with unrefined oil.

Grades of Olive Oil. Edible grades of olive oil sell for a considerably higher price than other vegetable oils, such as cottonseed oil and soybean oil that are produced in large volume. Aside from the traditional preference for olive oil, the principal justification for this difference in price is the flavor of the olive oil. Since flavor cannot be evaluated by chemical tests, the grading of olive oil is very difficult. Nevertheless, various grades and specifications have been set up by various governments and trade organizations. One of the main determinations relied upon is that of the free fatty acid content which is low in the high grade oils and tends to be higher the lower the quality of the oil. In mixtures of refined and unrefined oil, of course, the content of free fatty acid is no indication of the original quality of the oil. Regular dealers and large-scale users of olive oil no doubt rely more upon their experience in judging the quality of oil by its flavor and appearance than upon chemical tests and specifications.

U. S. Standards for olive oil include Grade A, or U. S. Fancy, with free fatty acid not more than 1.4 per cent; Grade B, or U. S. Choice, with F.F.A. not more than 2.5 per cent; Grade C, or U. S. Standard, with F.F.A. not more than 3 per cent; and Grade D, or substandard.

Good grades of virgin olive oil have a pleasing delicate flavor, which in the opinion of the present writer, justifies a high price for the oil as a luxury, but the strong flavor of the lower grade oils is too suggestive of fermentation and deterioration to be very delectable. Any reason for preferring refined olive oil for edible purposes over refined cottonseed oil, sufficient to justify double the price, is hard to find. Nevertheless, the public preference for olive oil is great enough to cause low grade oils and refined oils to sell at a high price. The strong flavored oils actually are in considerable demand at times for use in blended oils consisting of mixtures of a small proportion of olive oil with a large proportion of deodorized soybean or cottonseed oil. Even the extremely low grade material extracted from press residues sometimes is refined for edible use in "pure olive oil."

Characteristics of Olive Oil. Olive oil at ordinary room temperatures is fluid and clear. Its color varies from pale yellow through greenish yellow to green or greenish brown, according to the grade and method of preparation of the oil. The greenish color that often is thought of as being charac-

teristic of olive oil is not necessarily present and actually is not perceptible in much of the oil of the best quality.

Like any other fatty oil, olive oil will cloud when chilled to a temperature sufficiently low, and will deposit stearine when held at low temperatures. The temperatures required to cause these changes to occur vary over a considerable range for different specimens of olive oil. Oils that contain more than the average quantity of stearine, notably oils from certain districts of northern Africa, often are destearinized before being marketed, since oil that remains clear at 10°C ordinarily brings a higher price than oil which clouds at this temperature. Addition of a fractional percentage of blown cacao butter to olive oil will retard the deposition of stearine.

Some of the characteristics of olive oil are given in Table 16-15. The saturated fatty acids consist principally of palmitic acid, with a smaller quantity of stearic acid and traces of myristic and arachidic acids. Unsaturated acids consist mainly of oleic acid with a smaller quantity of linoleic acid. Small quantities of hexadecenoic acid have been found. The data show a large variation in the proportion of total saturated acids, and a tendency for oils having a larger than average proportion of saturated acids to contain also a larger than average proportion of linoleic acid. This tendency has been observed in the case of peanut oil also. Observations on linoleic acid obtained by crystallization of the fatty acids of olive oil from solvent were interpreted as meaning that the linoleic acid of this oil is a mixture of octadecadienoic acids, of which linoleic acid is the principal component.

TABLE 16-15. CHARACTERISTICS OF OLIVE OIL, EDIBLE AND PHARMACEUTICAL GRADES

	Usual range ^a	AOCS	U.S. standard	British standard	U.S.P., XIV
Acid value.....	0.2-6 ^b		(c)	2 max. ^d	2.8 max.
Saponification value.....	187-196	188-196		188 min.	190-195
Iodine value.....	79-90	80-88	79-90	79-88	79-88
Thiocyanogen value.....	75-83	79			
Hydroxyl value.....		4-12			
R-M value.....	0.2-1	1.0 max.			
Unsaponifiable (%).....	0.5-1.3	1.8 max.		1.5 max.	
Specific gravity, 15/15°C.....		0.914-0.919		0.915-0.918	
Specific gravity, 25/25°C.....		0.909-0.915	0.910-0.915		0.910-0.915
Refractive index, n_D , 25°C.....		1.466-1.468	1.4668-1.4683	1.468-1.471 ^e	
Refractive index, n_D , 40°C.....	1.4605-1.4635	1.460-1.464			
Solid. point (°C).....	0-6				
Titer (°C).....		17-26			17-26

^a Eliminating some of the more extreme of the published values.

^b Substandard grades of oil often have acid values much higher than this. Such oils often are refined before being consumed.

^c Different limits for different grades.

^d Unless otherwise agreed between purchaser and vendor.

^e At 20°C.

Sesame Oil

Primitive methods for extracting sesame oil from the seed are said to be still in use to some extent in parts of India and Africa and other sesame producing countries. These include pounding the seed in a wooden mortar, followed by treatment with hot water and skimming the oil from the surface, and the use of a type of animal powered mill known as the "chekku." Such methods probably have been largely superseded by modern oil milling methods. In former years, European practice was said to involve cold pressing of the crushed seed in hydraulic presses followed by one or more hot pressings, with the cold pressed oil being utilized as an edible oil without refining. It is doubtful that this procedure has widespread use at the present time. Probably most of the oil produced in large scale operations is refined before being used as an edible oil. Pressing in continuous screw presses or pre-pressing in screw presses followed by solvent extraction of the press cake are among the methods which can be used for the milling of sesame.

The crude oil varies in color, depending upon the method of milling and upon the color of the seed. Generally speaking, it can be refined and bleached to produce light colored oil without difficulty, provided that it is milled from well cleaned seed.

The properties of sesame oil have been described in a recent review which includes a bibliography of 254 references⁶. Characteristics of sesame oil and the composition of its fatty acids are summarized in Tables 16-16 and 16-17. The principal fatty acids of the oil are oleic and linoleic acids. Saturated acids amount to about 14 per cent of the total fatty acids and consist principally of palmitic and stearic acids. Linolenic acid appears

TABLE 16-16. CHARACTERISTICS OF SESAME OIL

	Usual range	AOCS	British standard
Acid value.....	1-6		5.0 max.
Saponification value.....	187-193	188-195	188-193
Iodine value.....	104-116	103-116	105-118
Hydroxyl value.....	1-10	10	
R-M value.....	0.1-1	2.8	
Unsaponifiable (%).....	0.9-2.3	Below 1.8	1.5 max.
Refractive index, n_D , 25°C..	1.470-1.474	1.470-1.474	1.472-1.476 ^a
Refractive index, n_D , 40°C..	1.464-1.468		
Specific gravity, 15/15°C.....		0.920-0.926	0.921-0.924 ^b
Specific gravity, 25/25°C.....	0.916-0.921	0.914-0.919	
Titer (°C).....	20-25	20-25	
Color, Lovibond, 1" cell.....			30Y-2.5R

^a At 20°C.

^b At 15.5/15.5°C.

TABLE 16-17. SPECIMENS OF SESAME OIL

Geographical Source	South Carolina	South Carolina	Nebraska	Nicaragua		India	India
Fat, % in seed.....	54.8	55.6	51.2	49.5			
Fat characteristics							
Acid value.....	1	3.6	3.0	4			
Saponification value.....	188.2	188.3	188.0	186.9		190	
Iodine value.....	111.5	111.6	109.8	112.8	110.6	109.6	114.1
Thiocyanogen value.....	76.2	76.1	75.3	75.0			
Hydroxyl value.....	1.1	4.1	3.3	4.2			
R-M value.....	0.2	0.2	0.1	0.1			
Polenske value.....	0.4	0.5	0.2	0.1			
Unsaponifiable (%).....	1.63	1.72	1.78	2.28		1.2	
Refractive index, n_D , 40°C..	1.4660	1.4671	1.4658	1.4664			
Specific gravity, 25/25°C....	0.9188	0.9192	0.9193	0.9207			
Titer (°C).....	23.1	23.7	23.6	23.5			
Color, Lovibond, 5¼" cell...	70Y-2.4R	70Y-16.7R	70Y-4.3R	70Y-4.0R			
Fatty acid composition, wt. %							
of total	(a)	(a)	(a)	(a)			
Saturated.....	12.8	12.9	13.6	13.8	13.0	14.2	16.3
Myristic.....					0.1		
Palmitic.....					8.2	9.1	9.4
Stearic.....					3.6	4.3	5.7
Arachidic.....					1.1	0.8	1.2
Unsaturated							
Hexadecenoic.....					0.5		
Oleic.....	42.1	41.6	42.1	37.3	45.3	45.4	35.0
Linoleic.....	43.4	43.8	42.4	46.6	41.2	40.4	48.4

^a Calculated as glycerides in the oil, with Unsap. present.

to be entirely lacking, since spectrophotometric analyses did not reveal the presence of any of this acid.

Sesame oil has a small positive optical rotation which is due to optically active minor constituents in the oil rather than to the presence of optically active fatty acids or glycerides. The oil contains a larger proportion of unsaponifiable matter than is usual for oils from seeds as rich in fat as is sesame seed. Also, the unsaponifiable fraction includes substances not found in other fats. These substances are responsible for some special properties of sesame oil.

The unusually great resistance of sesame oil and of hydrogenated sesame oil to oxidation is attributed in part to a phenolic material known as sesamol, which can be produced by hydrolysis from another substance known as sesamol in which occurs in the oil. Some other substances in addition to sesamol are believed to contribute to the unusual stability of the oil. An interesting property of sesame oil is its synergistic effect when used with pyrethrum insecticides. This effect has been found to be partly due to the substance known as sesamin which occurs in the oil and partly due to other substances probably closely related to sesamin.

Sesame oil may be used for soapmaking and for the various other purposes to which the nondrying vegetable oils are generally adapted, but its value as an edible oil is such that nearly all of the sesame oil produced is used as food. When available in the United States, it has been used largely as a component of vegetable shortenings, but it is well suited for use as salad oil, cooking oil, or as a component of shortenings and margarine fats.

Sunflower Oil

Sunflower seed may be milled by standard oil-milling procedures with hydraulic presses, continuous screw presses, or by extraction with solvent, with due regard for the fact that the kernels have a high oil content. Common practice is to decorticate the seed, leaving only a small percentage of hull with the meats for processing. A mill using continuous screw presses operated with hulled meats has been described. Probably most western hemisphere mills operate similarly. In the U.S.S.R. and eastern Europe, according to the older reference books, the general practice has been to subject the hulled and rolled meats to one cold pressing and one hot pressing in hydraulic presses, the cold pressed oil being usable as an edible oil

TABLE 16-18. SUNFLOWER OIL

	Range for 11 samples ^a	Range of av. values, 4 varieties ^b	Av. of 23 varieties ^c	Argentine oil ^d	AOCS
Fat characteristics					
Acid value.....	0.6-2.4	0.7-2	4.2	0.6	
Saponification value.....	190-191.6		191	191	188-194
Iodine value.....	113-142.9	122.4-136.6 ^b	130-135	131.6	125-136
Thiocyanogen value.....		78.4-81.3		75.5	
Hydroxyl value.....				2.0	14-16
R-M value.....					Below 0.5
Polenske value.....					Below 0.5
Unsaponifiable (%).....	0.3-1.3	0.7-0.8	1.05	0.56	Below 1.5
Refractive index, <i>n</i> _D , 40°C.....				1.4686	1.466-1.468
Refractive index, <i>n</i> _D , 25°C.....	1.4709-1.4749	1.4723-1.4738	1.4739		1.472-1.474
Specific gravity, 25/25°C.....					0.915-0.919
Specific gravity, 15/15°C.....				0.9243	0.922-0.926
Titer (°C).....					16-20
Solid. point (°C).....			Below -17		
Fatty acid composition					
Saturated.....	8.7-14.2	9.7-12.8	8.0		7
Unsaturated.....					86-88
Oleic.....	14.1-43.1	21.2-39.1			
Linoleic.....	44.2-75.4	51.2-68.3			
Linolenic.....		0.1% or less			

^a Oils from 10 samples of African seed and one from Argentina.
^b Values in this column are the range covered by average values found for each of four varieties, two tall varieties and two dwarf varieties. Each average is for 7 samples representing different localities. The range in I.V. for the individual samples was 108.6-139.7.
^c Canadian grown.
^d Commercial oil imported into Europe from Argentina

without refining other than clarification by settling. No doubt the trend is away from this practice as it has been in the case of other oilseeds.

Sunflower oil is a light yellow oil which is well suited for use as a salad and cooking oil, and when hydrogenated, for use in margarine fats and shortening. Good grades of the oil may be refined with a low loss. Total unsaturation of the oil is comparable with that of soybean oil but the linolenic acid found in soybean oil is lacking in sunflower oil, a fact which is to the advantage of sunflower oil when used as a food.

Some of the available data concerning the characteristics and composition of sunflower oil are given in Table 16-18. Individual samples of sunflower oil obtained from seed of different varieties grown in different years and localities cover a wide range of iodine values. Most of the oil found in commercial channels falls within a narrower range since lots of seed having extreme characteristics tend to become mixed with other lots during the commercial handling and milling of the seed. The iodine value and composition of the oil is influenced not only by the variety grown but also by the environment, including such factors as temperatures, soil fertility, and moisture supply. Oils differing from each other widely in iodine value differ in composition, mainly in the ratio of linoleic to oleic acid rather than in any large difference in total content of unsaturated acids.

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17. SEA FOODS

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Sources, Distribution and Types^{1, 2, 22.}

The oceans of the world, which superficially might appear to be barren, desolate and untenanted wastes are actually teeming with animal and plant life. They represent about 70 per cent of the surface area of the earth and are said to contain 10 parts per million, or a total of roughly 7.6×10^{12} tons of living or dead organic matter. Only a very small fraction of this material is ever utilized by man. Just prior to World War II the total fishery production of the world was estimated to be roughly 19×10^6 tons. The fisheries of the southern hemisphere have been poorly exploited, and until recently have yielded a meager 2 per cent of the total fishery production, most of the fish being taken from the North Atlantic and North Pacific oceans. Sea fish have been divided into four general classes, namely: (1) demersal or bottom dwelling (cod, haddock, hake, flounders, halibut, sole, etc.); (2) pelagic or surface swimming (herring, pilchards, anchovies, menhaden, tuna, mackerel, sharks, etc.); (3) anadromous, which migrate from sea to fresh water to spawn (salmon, smelts and shad), and (4) catadromous, which migrate from fresh to sea water to spawn (eels). It has been estimated that, of all fish caught, 41 per cent are used fresh or frozen, 33 per cent are reduced to fishmeal and oil, 16 per cent are salted or otherwise cured, and 10 per cent are canned.

Many varieties of sea life are consumed by man. One of these includes the so-called "shellfish," which are in reality marine invertebrates and which comprise two general groups, the molluscs (oysters, clams and scallops), and the crustaceans (shrimps, crabs, lobsters and crayfish). The economically important fishes are cold-blooded vertebrates and comprise two main groups, namely the elasmobranch fishes, which have cartilaginous skeletons, and the teleost fishes which nearly all have bony skeletons. Another very important group which includes the ocean mammals will be mentioned

later. In most countries the consumption of elasmobranch fish is very low in comparison with that of the teleost species. In most countries of the northern hemisphere shellfish tend to form a luxury item in the diet. The annual per capita consumption of fish is extremely variable and has been reported as being between 11 pounds in some of the central European countries to about 44 pounds in countries such as Japan and Norway.

Nutritive Value

General Composition^{1, 2, 5, 12, 20, 22}. Fish are not only a direct source of food for man, but also for the live stock from which he derives much of his nourishment. A very large body of information is available concerning the nutritive value of fish, especially from the point of view of the proximate composition of different types, and it is impossible to cover more than a small fraction of the available data. The flesh, or muscle portion, of fish rarely greatly exceeds half the total weight, and in some species, especially at time of spawning, is considerably less. It is only this portion of the fish which is normally consumed, except with canned varieties, and consequently the latter are almost invariably a better source of the mineral elements and vitamins. In certain countries, such as Malaya, it is customary for certain sections of the population to consume autolysates of whole fish. The following figures may be considered as fairly representative of the percentage composition of the edible (muscle) portion of some of the most common food fishes: total solids, 19 to 35 per cent; protein (nitrogen $\times 6.25$) 14 to 20 per cent; fat 0.2 to over 20 per cent, and ash 1 to 1.5 per cent. Usually the per cent of fat-free solids in different fish is very similar, but the fat content is extremely variable and in certain fish such as in Atlantic herring during the active feeding season may sometimes exceed 20 per cent.

Proteins^{1, 2, 5, 6, 8, 20}. The most important dietary function of fish is that of supplying readily digestible animal protein of high nutritive value. Over fifteen years ago it was shown that the general types of proteins in fish muscle and their distribution is very similar to that found in mammalian muscle. In general muscle tissue of teleost fishes appears to contain considerably less connective tissue or stroma proteins (about 3 per cent) than does that of the mammals (about 15 per cent), but this is not the case with elasmobranch fish. Until recently practically all information concerning distribution of the main muscle proteins was based upon the usually rather arbitrary procedures of extraction with neutral salt solutions of different ionic strengths or extraction with dilute acid or alkali. Data thus obtained have indicated that fish muscle is composed largely of very easily digestible globulins and albumins, e.g., actomyosin, globulin X, myogens and, possibly, myoalbumin. This division is undoubtedly crude, and information now available has indicated that there may be a much larger number of

proteins present in fish muscle than would be indicated by these earlier observations. Thus, extraction of fish muscle with neutral salt solutions of low ionic strength and subsequent analyses of these extracts by electrophoresis has shown that there are present a number of protein fractions, and that these differ considerably with different species of fish. Much work remains to be done concerning the distribution and types of fish muscle proteins and their enzymic or other significance.

The nutritive value of a protein lies not only in its digestibility, but in its complement of available essential, and other, amino acids. All available data, though admittedly variable, indicate that whole fish flesh is an excellent source of these amino acids. The results of amino acid analyses of flesh and certain organs of fish as given by different investigators are recorded in Table 17-1, together with average comparative figures which have been recorded for beef and pork. They show that, although the results of different workers do not always agree completely, fish flesh is at least comparable to meats with respect to its content of these essential amino acids. It is unfortunate that there have been few amino acid analyses of isolated fish muscle proteins, but available information for fish and lobster myosin indicates that the amino acid composition of this protein compares favorably with that of mammalian (rabbit) muscle myosin.

The biological value of fish flesh proteins has been determined almost invariably by feeding white rats dried preparations of the whole muscle from which the greater portion of the lipids has usually been removed by solvent extraction. For purposes of reference, the proteins of meat, whole eggs, or casein have usually been compared with fish in feeding experiments. Unfortunately no information concerning the food value of isolated fish muscle proteins appears to be available. The results of all feeding trials have shown that fish flesh proteins are at least as nutritious as those of meats; in fact, in one series of experiments, fish flesh proteins occasioned better growth of rats than did those of beef, the results being statistically significant. Fish liver protein is of high nutritive value, and recent information indicates that the proteins of whole fish eggs may also be of fairly high biological value. The outstanding food value of fish flesh proteins has recently stimulated interest in the preparation of canned baby foods from this source.

Lipides^{1, 2, 3, 4, 11}. The lipide content of fish flesh varies greatly with species and the degree of sexual maturity. It is usually stated that they exist mainly as triglycerides containing a large proportion of unsaturated fatty acids. Recent research makes it rather doubtful whether this statement applies, except possibly to the so-called "depot" fats. Thus it has been shown that the lipide fraction of fresh haddock flesh contains a variety of compounds including lecithin, free cholesterol, cholesterol esters, waxes, triglycerides, hydrocarbons, free fatty acids and plasmalogens. Inositol lipides and phos-

TABLE 17-1. DISTRIBUTION OF "ESSENTIAL" AND CERTAIN OTHER AMINO ACIDS IN EDIBLE FISH PRODUCTS AND IN CERTAIN MEATS (G. PER 16 G. OF NITROGEN)

	"Essential"										Tyrosine	Cys-tine	Glu-tamic acid	As-partic acid
	Arginine	Histidine	Isoleucine	Leucine	Lysine	Methionine	Phenylalanine	Threonine	Valine	Tryptophane				
Fish flesh (literature values to 1948)	4.6 -11.2	0.6 -2.3	5.2 -6.0	6.4 -7.1	5.7 -14.5	3.0 -3.8	4.3 -5.0	3.4 -4.5	4.3 -5.8	0.9 -2.2	0.4 -4.7			
Red cod (<i>Sebastes</i> sp.) flesh	4.3	1.6	6.8	11.4	14.4	2.6	4.4	5.1	5.0		0.4			
Herring (<i>Clupea pallasi</i>) flesh	5.9	2.0	6.4	8.0	8.2	2.2	4.5	4.5	5.1	0.7	2.2			
Swordfish (Atlantic) flesh	9.1	3.3	7.5	7.8	7.2	3.8	4.1	2.6	4.7	1.3				
Canned salmon (3 varieties)	5.5 -5.8	1.3 -2.6	4.9	7.3	5.7 -8.0	3.0	3.7	4.4	5.6	0.9 -1.4				
Canned cod and had-dock	6.1	2.1	5.5	8.1	8.8	3.0	3.9	4.9	5.3	1.0				
Canned herring (<i>Clupea</i> sp.)	5.5 -5.9	2.0 -2.4	4.9 -6.4	7.1 -8.0	7.8 -8.2	2.2 -2.7	3.4 -4.5	4.4 -4.5	5.0 -5.1	0.7 -0.8				
Canned sardine (<i>Sardinops caerulea</i>)	5.1	4.7	4.6	7.2	8.4	2.8	3.7	4.3	5.2	1.0			13	9
Canned tuna (3 varieties)	5.3	5.7	4.7	7.2	8.3	2.8	3.5	4.5	5.1	1.0			13	8.7

Lingcod (<i>Ophiodon elongatus</i>) "Myosin"	4.8	2.7	7.7	10.2	15.0	2.3	4.4	5.8	6.0	0.9	2.7		
Red cod (<i>Sebastes</i> sp.) liver	7.2	2.7	5.5	8.4	8.0	3.0	5.8	4.8	5.8	1.2	1.5		
Synthetic egg white from cod (German)	6.8	4.8	1.5	7.5	8.0	0.3	1.1	—	3.7	2.1	2.0	0.6	7.5 0.6
Mature salmon eggs (5 <i>Oncorhynchus</i> sp.)	7.1	2.8	7.3	10.0	8.8	2.9	4.9	5.9	7.3	1.0			
Beef (Literature values)	5.7 -10.1	0.6 -4.4	5.2 -5.9	7.5 -8.6	7.3 -10.0	2.5 -4.1	3.6 -4.9	3.5 -5.3	5.1 -5.3	0.9 -1.5			
Pork (Literature values)	6.4 -6.6	2.2 -3.8	5.1 -5.9	7.2 -8.6	8.7 -8.7	2.4 -3.4	3.7 -4.2	4.5 -4.8	5.3 -5.4	1.2 -1.4			

phatidylethanolamine have also been identified. It is to be hoped that further work with other fish containing a higher percentage of total muscle lipides than does haddock will be carried out.

It has been stated that fish lipides are 95 per cent digestible and readily absorbed from the intestinal tract. They are apparently a relatively poor source of the essential fatty acids. Though fish is probably largely consumed as a source of nutritious proteins, the lipides are valuable as energy foods, and undoubtedly contribute much to the desirable flavor of fatty fish such as salmon and herring. The unsaturated nature of many of the fatty acids renders fish particularly liable to develop oxidative rancidity with attendant flavor deterioration.

Though the greater proportion of marine fats consumed by man is undoubtedly eaten with the flesh, some are extracted for food use. In Europe marine oils are used in the manufacture of edible fats such as margarine, though in North America the existing large vegetable oil resources practically preclude their use for this purpose. In the Pacific northwest oil from cooked salmon heads and trimmings is sometimes added to salmon flesh of low oil content prior to canning. In Norway economies have forced certain canneries to add polymerized and deodorized herring oil instead of olive oil to sardines.

Vitamins^{2, 3, 4, 7, 11, 16, 20, 22}. Fish, especially their viscera, are collectively a rich source of most of the vitamins required by man. That fish liver and visceral organs are the richest natural suppliers of the A and D vitamins is now common knowledge. The distribution of these vitamins is extremely variable with different species, and is moreover affected by season and sexual maturity. Oils from the livers of tuna species and from halibut may contain from about 100,000 to one million international units of vitamin A per gram of extracted oil. Flesh of fatty fish usually contains a small amount of vitamin A, as is indicated in Table 17-2. Thus, a normal serving of canned fish usually contributes less than 10 per cent of the daily vitamin A requirement. However, several of the more fatty types of canned fish such as mackerel, sardines and salmon are stated to be good sources of vitamin D. There is little available information regarding the distribution of vitamin E in fish, though cod roe has been named as a good source, as well as certain fish liver oils.

Prior to 1943 there was only a meager amount of information concerning the distribution of vitamins of the "B complex" in fish, but since that time further data have been published concerning certain species. Feeding trials with white rats carried out about 1946 showed that flesh of white fish was a very poor source of thiamin, riboflavin and pantothenic acid in comparison with pork, a poor source of these three vitamins in comparison with beef, and was also somewhat deficient in pyridoxine and nicotinic acid. In these

trials the flesh of salmon was found to contain appreciable amounts of pantothenic acid. Available data concerning the distribution of various vitamins in the edible portion of fish, shellfish and whales are shown in Table 17-2. The results given for riboflavin, thiamin and pantothenic acid in flesh of white muscled fish indicate that they contain less of these vitamins than does beef, and would therefore bear out those obtained in the above feeding trials. In general the content of nicotinic acid in fish muscle is similar to that of beef. Shellfish appear to contain more thiamin and riboflavin than most fish. Clams are a rich source of cobalamins (vitamin B₁₂), and this is true of most other marine invertebrates which have been examined. Livers, kidney, spleen and digestive organs of fish have also been found to be good sources of this and other "B complex" vitamins where analyses have been made.

Fish livers and other visceral organs are not often consumed by man but are in general excellent sources of vitamins A and D and also of vitamins of the "B complex." For the sake of brevity literature values concerning the vitamin distribution in these various internal organs of fish have not been included in Table 17-2.

Minerals^{2, 11, 12, 20, 22}. In general, sea fish have a much higher iodine, and lower iron, content than lean beef. Average figures for the mineral content of the edible portion of some common fish and shellfish are as follows (mg per 100 g wet weight; the approximate daily adult requirement for calcium, iodine and iron in mg is given in parentheses).

	Fish	Shellfish
Calcium (80).....	10-100	29-320
Magnesium.....	10-32	24-414
Phosphorus.....	111-296	110-240
Iodine (0.05-0.10).....	0.1-5.9	0.9-13.8
Iron (12).....	0.50-2.0	0.75-26
Copper.....	0.04-0.17	0.3-3.73

Canned fish in which the bones are included usually have over 0.2 per cent of both calcium and phosphorus. It has been stated that a normal serving of such fish will supply 28 to 54 per cent of the daily calcium requirement of man, 24 to 44 per cent of the phosphorus, and 7.5 per cent of the iron. Fish is one of the richest natural sources of fluorine, and also contains some cobalt. It appears that shellfish have a considerably higher calcium and iodine content than fish.

Microbiological Spoilage and its Control^{14, 15, 18, 19, 21}

Microorganisms Involved and their Metabolism. Flesh and internal organs of healthy sea fish are sterile bacteriologically, while the slime and digestive tracts of feeding fish support a qualitatively and quantitatively variable bacterial flora. It is these organisms which largely account for the

TABLE 17-2. DISTRIBUTION OF CERTAIN VITAMINS IN THE EDIBLE PORTION OF FISH, SHELLFISH AND WHALES (WET WEIGHT BASIS)

	Thiamin ($\mu\text{g/g}$)	Riboflavin ($\mu\text{g/g}$)	Nicotinic acid ($\mu\text{g/g}$)	Folic acid ($\mu\text{g/g}$)	Panto- thenic acid ($\mu\text{g/g}$)	Pyri- doxin ($\mu\text{g/g}$)	Biotin ($\mu\text{g/g}$)	Cobalamin (vitamin B_{12}) ($\text{m}\mu\text{g/g}$)	Vitamin A (I.U./ 100g)	Vitamin D (I.U./ 100 g)
Croaker (<i>Micropogon undulatus</i>)	0.76-0.81 1.55	1.0-1.09	55-59							
Halibut (<i>Hippoglossus stenolepis</i>)	0.3-0.82	0.36-0.62 1.85	30-35 61							
Halibut (<i>Hippoglossus hippoglossus</i>)			41-52							
Pacific flounders (8 species)	0.41-0.68	0.37-0.57								
Lingcod (<i>Ophiodon elongatus</i>)	0.36-0.62	0.28-0.50								
Rock or Red Cod (3 species of <i>Sebastes</i>)	0.29-0.81	0.90-1.53						20		
Sable fish (<i>Anoplopoma fimbria</i>)	1.05-1.20	0.77-0.98								
Herring (<i>Clupea</i> species)	0.11-0.40	1.81-1.72							20-400	300-700
Pacific salmon (species of <i>Oncorhynchus</i>)	0.80-1.48 0.4-2.1	0.46-2.31 1.80-2.50	84				0.098		900-1500 440-5250	190-800 500
Cod (<i>Gadus morhua</i>)	0.40-0.50 0.15-0.98	0.46-3.1 0.19-0.25	17-30 23-33		0.81-1.5			1.8-10.0	50	0
Haddock (<i>Melanogrammus aeglefinus</i>)	0.10 0.3-0.5	1.65 0.14-0.19	9 32-43		0.38-1.5			5.6-18.0	50	

Atlantic mackerel (different sp.)	0.5-2.0 1.7	6.6 3.1	55-72 94		9.0			150	700
Dogfish (<i>Squalus acanthias</i>)	0.5								
Skate (<i>Raja</i> sp.)	0.2-3.0							1585	
Swordfish (Atlantic)	0.53	0.49	91		0.5		0.012		
Canned salmon (<i>Oncorhynchus</i> sp.)	0.18-0.52	1.6	74	0.005	5.8	4.5	0.15		
Canned tuna	0.4-0.66 0.1-0.36	0.9-1.5 0.7-1.2	102-155 104-154	0.006 0.006-0.032	3.5-5.6 4.5-9.2	3.7-5.2	0.03-0.06		200-333
Canned herring (<i>Clupea harengus</i>)	0.03-0.28	0.16-0.23	38-59	0.008-0.027	4.2-5.4	1.3-2.0	0.03-0.06		
Canned sardines (<i>Sardinops caerulea</i>)	0-0.19	2.3-3.7	62-88	0.005	4.9-8.3	2.4-3.0	0.19-0.34		250-333
Canned mackerel (<i>Scomber scombrus</i>)	0.04-0.86	1.7-2.6	50-66	0.009-0.022	2.5-4.0	1.8-2.6	0.03-0.04		165-250
Canned mackerel (<i>Scomber pneumatophorus</i>)	0.18-0.38	2.9-3.8	80-94	0.006	4.3-5.4	2.5-2.9	0.12-0.23		
Pacific clams (various species)	0.69-1.39	0.98-2.69						250-310	
Mussel (<i>Mytilus edulis</i>)	1.62	2.49						120	
Pacific shrimp (2 species)	0.47-0.57	1.33-1.42							
Crab (<i>Cancer magister</i>)	1.7-1.82	0.16-0.24							

TABLE 17-2—Continued

	Thiamin ($\mu\text{g/g}$)	Riboflavin ($\mu\text{g/g}$)	Nicotinic acid ($\mu\text{g/g}$)	Folid acid ($\mu\text{g/g}$)	Panto- thenic acid ($\mu\text{g/g}$)	Pyri- doxin ($\mu\text{g/g}$)	Biotin ($\mu\text{g/g}$)	Cobalamin (vitamin B ₁₂) (m $\mu\text{g/g}$)	Vitamin A (I.U./ 100 g)	Vitamin D (I.U./ 100 g)
Atlantic oysters	0.98-1.80									
Whale meat (Blue and fin whales)	0.21-0.74	1.98-3.94	37.9-59.4							
Whale meat (Mixed Baleen meat)	0	7.6	205		5.0			30-200		
Beef	0.8-3.0 0.7	0.4-3.5 4.1	30-100 52.7		2-13	2-4.5		10-30		

Where two values are given for a given vitamin they represent results obtained by different investigators.

The daily suggested average requirement of the above vitamins for an adult is: Thiamin: 1800 μg . Riboflavin: 2600 μg . Nicotinic acid: 18,000 μg . Folic acid: Not established, may be 100-200 μg . Pantothenic acid: Not established, possibly midway between that for thiamin and nicotinic acid. Pyridoxin: Not established, may be 1500 μg . Biotin: Not established. Cobalamin: Not established. Vitamin A: 5,000 I.U. Vitamin D: 500 I.U.

rapid spoilage of fish *post mortem*; autolysis plays a minor role and is invariably overshadowed by alterations due to bacteria. Organisms of the following genera are largely responsible for bacterial spoilage of fish: *Achromobacter*, *Pseudomonas*, *Flavobacterium*, *Micrococcus*, *Corynebacterium* and *Mycoplana*. Less frequently *Proteus*, *Sarcina* and *Bacillus* are implicated. Strict sporogenous anaerobes of the genus *Clostridium*, and *Escherichia coli*, occur only occasionally, and usually have their origin in contaminated waters. For some types of fish there seems to be a generic succession of bacteria during spoilage, *Micrococcus* and *Flavobacterium* species being followed by the more proteolytic *Pseudomonas* and *Achromobacter* organisms.

Bacterial spoilage is accompanied by breakdown of the muscle carbohydrates, proteins and lipids, and due to variations in the composition of different fish and the complex nature of the bacterial populations involved, there appears to be no consistent degradative pattern. The muscle lactic acid which arises *post mortem* through glycogenolysis is said to yield acetic acid and carbon dioxide following bacterial oxidation. The muscle glucose is believed to be broken down to yield lactic and formic acids, ethyl alcohol, acetylmethylcarbinol and carbon dioxide. It has been established recently that d-ribose occurs in fish muscle *post mortem*, frequently in excess of the glucose present, but its possible degradation by fish spoilage bacteria has not yet been investigated. Free amino acids and peptides in fish muscle are probably deaminated with formation of ammonia, and the trimethylamine oxide present is usually reduced to trimethylamine. Appreciable hydrolysis of the muscle proteins probably occurs only in the more advanced stages of spoilage. Most evidence indicates that at least some of the lipids of fish muscle, which as has already been shown exist in a variety of forms, are hydrolyzed slowly during the later stages of bacterial spoilage with the formation of free fatty acids. The most serious deterioration of lipids is that due to oxidation which results in formation of fatty acid hydroperoxides. These are subsequently further decomposed to yield aldehydes and other compounds which have a serious adverse effect on flavor. There is some evidence which suggests that the generally observed slower rate of bacterial spoilage of fatty fish as opposed to lean fish is due to the hydroperoxides which are known to exert a bacteriostatic effect.

Effect of Physical Conditions on Development of Microorganisms in Fish. The bacteria usually associated with fish, and which occasion its spoilage, are mainly psychrophilic in nature, most of them developing at 0°C. Many will grow at -5° or even -7.5°C. About 25 years ago it was found that the temperature coefficient for the growth of most of these organisms was much greater at temperatures near 0°C than at higher temperatures. Thus the growth rate of fish spoilage bacteria was roughly doubled by increasing the incubation temperature from -1 to 2.5°C.

The practical implication of this discovery is obvious, for it means that by holding fish at -1°C (which is approximately the freezing point of fish muscle), instead of at slightly higher temperatures its storage life is roughly doubled. Unfortunately this finding has not yet been applied to any significant extent, perhaps largely due to the practical difficulties involved. However, interest in this finding has been revived again recently, and tests are being conducted in several areas to determine the practicability of holding fish or shellfish in tanks of sea water which are maintained at about -1°C and are installed on fishing boats.

The pH of fish muscle *post-rigor* usually varies from 6 to 7, and this variation in the reaction is probably influenced to an important extent by its initial glycogen content. It has been demonstrated that not only does a more acid reaction hinder bacterial spoilage, but that it also seems to decrease the rate at which trimethylamine is formed. Attempts have been made to improve the keeping quality of fish fillets by acid treatment, but these are impractical since the muscle proteins lose free liquid as they approach their isoelectric zones.

Freezing usually causes some reduction in the viable bacterial population of fish flesh, but at normal cold storage temperatures (e.g., -20°C) there is little further decrease for many months. High cold storage temperatures (e.g., -7°C) occasion a more rapid decrease in the numbers of viable bacteria in stored fish, but this has little practical significance since at these high storage temperatures undesirable changes such as oxidative rancidity and denaturation proceed at an accelerated rate.

The terms "drying" and "dehydration" have been used somewhat loosely, apparently to distinguish respectively natural and artificial removal of water from foods. As the water content of foods decreases, microorganisms find their growth increasingly difficult. With dehydrated fish stored at 25°C it has been reported that slight mold growth, which was not visible to the eye, occurred at 75 per cent relative humidity corresponding to a water content of 13.2 to 13.6 per cent. On similar material bacteria grew at 85 per cent relative humidity corresponding to a 19 to 19.7 per cent water content. *Micrococci*, which resist drying procedures better than *Pseudomonas* and *Achromobacter* species, tend to occur to the exclusion of most other types of bacteria in dried fish. Drying procedures offer excellent opportunities for aerial and other contamination, so that the products obtained may be highly contaminated with microorganisms.

Ultraviolet radiations have been used experimentally to retard fish spoilage, but rather extensive treatment occasions only a slight quality improvement. Ionizing radiations offer greater promise, for a very brief exposure to cathode rays will usually destroy most of the viable bacteria on thin fish fillets. However, before such a process can be used industrially it will be

necessary to overcome side reactions which adversely affect the flavor of treated fish. Some progress has already been made in this direction.

Effect of Chemicals on Growth of Bacteria in Fish. Ordinary salt is undoubtedly the most widely applied chemical preservative which is used with fish. Its efficiency apparently depends on a number of effects prominent among which are osmotic action and resulting dehydration; possible toxic action of high concentrations of chloride ions, relative insolubility of oxygen in strong brines and depression of the activity of various enzymes. Factors such as concentration, rate of penetration, degree of contamination with halophilic or salt tolerant organisms and cold storage temperatures determine the relative effectiveness of salt as a preservative. Experiments have indicated that pure sodium chloride is a more effective preservative when it is not contaminated with magnesium or calcium salts. The red discoloration of salted fish appears to be due largely to development of halophilic species of *Serratia* or *Sarcina* which do not develop appreciably on fish at temperatures below 10°C. These organisms develop in media saturated with respect to sodium chloride, and strict halophiles will not grow when the salt content falls below about 6 per cent. Another defect which occurs in salted fish is "dun," a brown discoloration caused by sporendonema molds (e.g., *S. epizoom*). From the practical standpoint, treatment of these defects has proved difficult. The use of salts which are not heavily contaminated with halophilic organisms is helpful, but sterilization of salts which has been advocated from time to time does not appear to be practicable. Thorough disinfection of infected premises is of value; and addition of 0.25 per cent sodium benzoate plus 3 per cent Na_2HPO_4 to the salt used in curing has been found of some value in preventing discoloration. Recent work has shown that sorbic acid in less than 0.1 per cent concentration largely prevents development of "dun" discoloration of salt fish, and of molds on smoked fish.

Attempts have been made to delay bacterial decomposition of fish by treatment with various chemicals applied in a gaseous state. Of these substances carbon dioxide has been studied most extensively. High partial pressures of this gas are required to exert an important bacteriostatic effect. Thus, 50 per cent carbon dioxide in air causes optimum bacteriostasis, while less than 40 per cent is inadequate. The effect of carbon dioxide on the physical appearance of fish, as well as the difficulties of its application, appear to have prevented its utilization. The mechanism of the bacteriostatic action of carbon dioxide does not appear to be fully understood. Nitrogen in similar concentrations is not nearly as effective.

The possibility of employing other gases to retard bacterial spoilage of fish has been investigated. Both ethylene oxide and propylene oxide have

been found to be extremely effective, but they occasion several undesirable alterations in treated flesh and are therefore valueless in practice.

A very large variety of chemical substances has been used to preserve fish both experimentally and under practical conditions. The most commonly employed substances have been sodium benzoate or the free acid, its ethyl and methyl esters, hexamethylenetetramine and boric acid. A few countries permit the inclusion of these substances in fish or in acid-cured fish products, but on the North American continent their use is either barred or strongly discouraged. While benzoates may exert noticeable bacteriostatic activity in acid-cured raw fish products, they are practically valueless as preservatives at or near pH 7, though they do suppress trimethylamine formation markedly. Since about 1939 sodium nitrite has found wide application as a bacteriostat for fish in Canada where it was legalized for domestic use in 1949. It is not permitted in the United States. In Norway sodium nitrite is permitted for use as a preservative for raw herring prior to reduction, but meal from fish so preserved must not be exported. This substance has a pronounced retarding effect on bacterial growth at pH values below about 6.5. Above this pH value its bacteriostatic activity decreases, and at pH 7 it is ineffective in permitted concentrations. As with benzoate, nitrites strongly inhibit formation of trimethylamine, and it would seem possible that this is due to inactivation of the enzyme triamineoxidase. The mechanism by which nitrites exert their inhibiting effects on bacterial growth is not as yet clear. It was suggested many years ago that there might be a diazo reaction between amino groups of certain enzymes, or enzyme activators, and the nitrite ion, with consequent inactivation of the former. Hydroxylamine also inhibits bacterial spoilage of fish strongly. It is as effective as sodium nitrite when used in considerably lower concentrations, and exerts its bacteriostatic action equally well at pH values below and above 7. However, it has been shown to have an appreciable cumulative toxic effect in experimental animals which is apparently lacking with nitrites.

Within the past two years some interest has been evidenced in the possibility of retarding bacterial spoilage of fish with antibiotics. Outstanding preservative effects have been obtained with very small amounts of Aureomycin. Several practical methods of application of this antibiotic have been investigated, including incorporation of 1 to 4 parts per million into ice used for icing fish, addition of about 2 parts per million to chilled sea water used for holding fish on boats, and dipping fish for one minute in solutions containing about 50 parts per million before they are iced. All these methods have indicated exceptional preservative effects. Experiments have also indicated that cooking fish in the usual manner destroys at least 50 per cent of the Aureomycin. Other antibiotics proved considerably less efficacious or were quite valueless for this purpose.

The types of lightly smoked fish which are presently offered for sale are highly perishable, and will keep only slightly longer than fresh fillets which are held under similar conditions. The superior keeping quality of lightly smoked fish is presumably due to the influence of brining, slight drying, and possibly to the antibacterial action of the phenolic constituents of wood smoke.

Methods of Determining Bacterial Spoilage of Fish. With few exceptions tests for determining fish quality have been only methods for detecting bacteriological deterioration, and have not taken into account other causes of spoilage such as are occasioned by oxidative rancidity or myosin denaturation. Methods of assessing bacterial spoilage of fish other than those based on organoleptic ratings have been quantitative determinations of the bacterial populations involved or of their metabolic products. Unfortunately no one method is likely to prove entirely satisfactory unless used as a condition test: that is to say, where it is employed with a certain type of fish or fish product under a rather similar or identical condition of preparation and storage. This is because the predominant microflora is variable; the types which develop depending on the variety of fish, its chemical composition, the storage temperature, whether the fish are whole, eviscerated or cut as in filleting, and other factors. Different portions of a whole spoiled fish may have very different total bacterial populations.

Both viable and direct determinations of the bacteria in fish flesh have proved valuable as a means of assessing quality and the latter has the advantage that it can be carried out extremely rapidly. There is little doubt that such a method offers greater promise than most chemical methods both as regards sensitivity and reliability. This is especially true if a direct bacterial count is used in conjunction with an incubation technique; such a test being designed to determine the potential keeping quality of the sample.

It would be impossible to discuss the many and varied tests for bacterial spoilage of fish which have as a basis the measurement of a product or products of bacterial metabolism. In general, tests for hydrogen sulfide, indole, total volatile bases, trimethylamine, dimethylamine, ammonia, total volatile reducing substances, and "tyrosine" fall into this category. Certain of these have proved useful under a given condition, and others have shown little promise. Sometimes one is tempted to think that some of the time and energy which is devoted to designing new, or attempting to improve older, quality tests, could be better spent in research designed to produce products which are of such high quality that such tests need not be applied.

Frozen Fish^{11, 16, 20, 22}

During the past few decades freezing of fish has become a very important industry, but it has taken many of those engaged in the processing and dis-

tribution of frozen fish a long time to realize that this commodity is very susceptible to undesirable storage changes. It is very unfortunate that much of this product which has reached the market has been of such poor quality that the general public has often associated the term "frozen fish" with an inferior article. If adequate care is taken, frozen fish can be kept many months in excellent condition. Precooked frozen fish is now being marketed, and presents rather special problems in preservation.

Probably the single most important cause of deterioration of frozen fish is denaturation of the myosin fraction. This was first realized about 1930 when it was demonstrated that when smoked haddock was prepared from fish which had been frozen and then stored for months at relatively high storage temperatures (e.g., -5°C), it did not exhibit a normal surface gloss. This was subsequently shown to be due to a denaturation of the muscle myosin protein which was accelerated by slow freezing, but more particularly by storage of fish at unfavorable temperatures (e.g., above -20°C and more particularly at about -3.5°C). Under these conditions myosin became increasingly insoluble in neutral salt solutions such as curing brines and the "glossy pellicle," which is apparently due to peptized myosin, and is associated with good smoked cured fish, became less apparent or was absent. Myosin denaturation unfortunately still plays a very prominent role in occasioning quality deterioration in frozen fish, and it is now well known that it may be retarded very greatly by storing fish at temperatures well below -20°C , and preferably at -30°C .

Some information regarding the effects of such physical factors as salt concentration and pH on extractability of myosin and on its denaturation while frozen has been obtained. However, there has been little or no advance in our knowledge of the actual mechanism by which this denaturation occurs nor how it may be prevented. Since the myosin fraction of fish muscle is said to represent from about 65 to 75 per cent of the total protein, and denaturation is accompanied by, and may possibly cause, an organoleptic dryness or toughness of the flesh, the economic importance of the problem is apparent.

The deterioration of fats in frozen fish is largely due to their oxidation, and is thus usually termed "oxidative rancidity." The mechanisms involved are complex, but it is known that unstable fatty acid hydroperoxides form at the unsaturated linkages, and that these subsequently break down to yield aldehydes and other compounds. Slight fat oxidation may seriously affect the flavor of fish, especially if it is rich in fat. Though oxidative rancidity may develop in fresh fish, or in fatty canned fish which is allowed to stand for a day or more after opening, it is largely a defect of cold stored fish. It was established over 15 years ago that the oxidation of fat in frozen fish is catalyzed by haem compounds of the muscle such as myoglobin and

cytochrome. Since these compounds occur in high concentration in the brown lateral muscle, it was found that this tissue was particularly liable to become rancid. Early work established that oxidative rancidity could be retarded considerably by storing fish at temperatures well below -20°C (e.g., -30°C), but unfortunately such temperatures are rarely available commercially. Other retardative measures have been suggested, and some have been applied. A good ice glaze, perhaps with inclusion of ascorbic acid which itself oxidizes and thus tends to remove oxygen, is probably the most valuable combative measure. Immersion of fillets or steaks in solutions of antioxidants such as ascorbic acid, sodium ascorbate or ethyl gallate have been found to convey a variable measure of protection against discoloration due to flesh pigment oxidation and also against flavor deterioration. Of these substances ascorbic acid has been most widely applied, but reports regarding its efficacy have been very conflicting. There have been a limited number of continuing commercial applications. Failure to apply sufficient ascorbic acid and to freeze fish promptly following its application may have contributed to the apparent lack of protection in some instances. Other preventive methods include exclusion of air and storage in an inert gas such as nitrogen, but these have not been adopted commercially apparently due to packaging difficulties. The use of properly applied vapor-proof wrapping materials is also of considerable value in retarding fat oxidation.

Canned Fish^{9, 22}

In the early days of fish canning it was not unusual to find occasional cans which were spoiled as a result of bacterial action. At the present time bacteriological spoilage of properly canned commercial fish such as salmon, tuna and sardines is very rare. These fish will normally withstand adequate sterilization without serious flavor alterations. However, certain fish, particularly those with white flesh, will often undergo brown discoloration when sterilized at temperatures normally considered desirable for fish, this alteration being apparently largely due to Maillard types of reactions. Hence there is a tendency for material of this kind to be under-processed in order to preserve its natural white appearance, and consequently for it to undergo bacterial spoilage. Maillard browning may be alleviated by using a precook method in which much of the free exuding liquid is discarded. Such a procedure is merely palliative and more research is needed in order to attain conditions which will permit adequate sterilization of such fish without undesirable flavor alterations. Experimental or practical approaches to this and other problems which arise during canning which must be mentioned are: (1) use of vacuum cooling coupled with free liquid removal from precooked fish prior to canning it so that both undesirable volatile substances and soluble materials are removed; (2) the use of sodium citrate as

an agent to prevent blue discoloration of canned crab; (3) attempted enzymic removal of free ribose from fish muscle in order to decrease Maillard browning, and (4) attempts to apply antibiotics or penetrating radiations as agents to occasion partial or entire sterilization of the product and thus to permit retorting at low temperatures. These, and problems such as elucidation of flavor improvements which occur on "aging" canned fish, confront those engaged in the canning industry.

Whales^{15, 16}

Whales, dolphins and porpoises are the only mammals which live entirely in water. Blue and fin whales accounted for 65 per cent of the 1949 to 1950 catch, the remainder being humpback, sei, or sperm whales. It has been estimated that the 26,504 whales captured in the Antarctic during the 1950-1951 season would yield 186,000 to 265,000 tons of lean meat. However, only a small proportion of whalemeat is actually consumed directly at present, much of it being reduced to meal, the blubber yielding oil which is of considerable economic value in the manufacture of edible fats. Whalemeat has a very variable oil content, which may be from 0.3 to 13 per cent in the back fillets, that from pregnant females having the most. The general composition of whalemeat closely approximates that of mammalian muscle except that it contains very small quantities of trimethylamine oxide and methylamines. The fats are, however, typical of those of marine origin and contain large proportions of highly unsaturated C₂₀ and C₂₂ fatty acids. The dark red color which is generally found in whale muscle is due to the relatively high myoglobin content which varies from about 0.62 to 0.70 per cent. This is considerably higher than that of the ox (0.33 to 0.45 per cent) and pig (0.28 to 0.44 per cent). The warm-blooded nature of whales and the usually high fat content of the flesh raises rather special problems of preservation. Bacterial spoilage is mainly anaerobic in nature and strict anaerobes of the genus *Clostridium* are largely responsible. It is imperative that whalemeat destined for human consumption be either chilled, canned, or frozen and stored as soon as possible after capture. The practices of bleeding and slitting so that the visceral cavity is cooled by the sea water appear to be beneficial where the whales must be towed considerable distances before reaching processing plants. Neither of these procedures obviates the need for prompt processing for the huge masses of the whale fillets only permit very slow cooling. Development of oxidative rancidity in frozen whalemeat is a serious problem. Experiments have shown that the usual sensible measures employed with fish will retard this development. Thus, adequate glazing, wrapping with polyvinylidene film which is "shrunk on" by evacuation, and incorporation of antioxidants such as ascorbic acid or ethyl gallate have proved valuable deterrents. Probably very low cold storage temperatures such as -30°C would retard oxidative rancidity.

Seaweeds and Their Uses¹³

The value of seaweeds in human nutrition would appear to be more indirect than direct, since their products are used generally for their physical value as gelling agents and stabilizers. The various polysaccharides which they contain would appear to be undigested by man, though ruminants are apparently able to utilize them. Many species of seaweeds are a good source of ascorbic acid and some contain appreciable, though variable, amounts of certain vitamins of the "B complex" such as thiamin, riboflavin and cobalamins. In certain countries such as Scotland, Hawaii, Japan and China various species of seaweeds are consumed as a vegetable, or else are used to prepare special dishes. Thus dulse (*Rhodymenia palmata*) and laver, or Japanese "Nori" (*Porphyra* species), are eaten in large quantities. Seaweeds probably have no important value as protein foods.

One of the most important uses of seaweeds is the preparation of polysaccharides such as algin, carrageenin and agar, all of which have found valuable uses in the food industries. Alginic acid or algin is derived largely or entirely from brown algae such as the kelps (*Laminaria* and *Macrocystis*), and fucus species, in which its distribution varies with species and season, and is usually about 15 to 40 per cent of the total weight. It is nontoxic and has found extensive use as a stabilizer for ice cream, for which purpose it appears to be preferable in most respects to gelatin, and for chocolate milk. Other uses include stabilization of various packaged puddings, mayonnaise, cheese spreads, etc.

Irish moss is gathered on the Eastern seaboard of the United States and Canada where it is used to prepare carrageenin. This substance is composed largely of galactose units joined at the 1,3 position, and has a sulfuric ester group on the C₄ atom. Some glucose and pentose residues have also been found. It is used for its thickening, viscosity producing, emulsifying and gelling properties.

The term "agar" is very loosely employed to describe phycocolloids of rather similar gelling properties. Thus the following definition has been proposed: "The gel-forming extractive of gelidium, gracilaria and other red algae (which) is insoluble in cold water but soluble in hot water, a 1 per cent solution of which forms a firm gel." This definition would automatically differentiate agars from carrageenin and alginic acid. There are possibly a number of chemically distinct agars. One proposed formula for agar is that of a chain of 9-d-galacto pyranose residues attached by 1,3-linkages, there being one terminal l-galactose reducing residue. Agar has a variety of uses in foods besides those of the laboratory and pharmacy. It is like the other phycocolloids in that it can serve as an emulsifier, thickener, and gelling agent. There are, however, specific uses for which agar is normally the colloid of choice. It has a variety of uses in the confectionery and baking industries, and as a stabilizing agent in certain types of cream cheese.

Agar is frequently used, occasionally admixed with gelatin, as a gelling agent for canned meats since its gels have a very high melting point.

Recently considerable interest has been aroused in preparation of certain chemicals from seaweeds. Thus mannitol, fucose, and citric acid have been prepared from different types of sea algae.

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18. ANIMAL PRODUCTS

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Meat and meat food products include the skeletal tissues of cattle, swine, sheep, poultry, and game; and the organs which may be used as food, such as tongue, liver, kidney, heart, pancreas, brain, thymus, and spleen. They constitute an important part of the diet because of their high content of excellent quality protein and essential vitamins.

Animals play an important role in our agricultural economy. They convert large quantities of roughages and cereals not suitable for human consumption into food products of superior nutritive value. Animals furnish many by-products important in our national economy, including hides, skins, pharmaceuticals, etc. Animal agriculture contributes greatly to the control of erosion and maintenance of soil fertility. A well developed animal agriculture serves as a reserve food supply that can be drawn upon in emergencies. For the years 1951 to 1953, income from farm animals represented from 28 to 34.4 per cent of the farm income in the United States.

Production and Consumption

The meat packing industry pioneered in the development of mechanical handling, continuous-line production, and use of refrigeration in processing, storage, and transportation. It is one of the largest industries in this country. The total value of products shipped amounts to approximately ten and one-half billion dollars annually.

The average annual production of meat in the United States for the years 1946-50 was over 22 billion pounds, and for 1953 was nearly 25 billion pounds. The average annual per capita consumption for 1946-50 was 151 pounds, and for 1953, 154 pounds. Beef and pork make up the major portion of meat consumed in the United States. The quantity of meat consumed varies in different sections of the country and with the economic status.

TABLE 18-1. PRODUCTION OF MEAT IN THE UNITED STATES IN 1953
(Millions of Pounds: Carcass Weight, Exclusive of Variety Meats)

	Beef	Veal	Lamb and mutton	Pork	Total
Federally inspected	9,368	882	644	7,293	18,187
Other wholesale and retail	2,687	569	71	1,678	5,005
Farm slaughter	389	108	14	1,092	1,603
Total	12,444	1,559	729	10,063	24,795

Table 18-1 shows the production of meat in the United States for 1953. Table 18-2 shows the production and per capita consumption of meat in specified countries.

Grades of Meat

The United States Department of Agriculture has established grades of carcass beef and wholesale cuts as follows: prime, choice, good, commercial, utility, cutter, and canner. The highest grade prime is obtained from high quality steers and heifers fed to a high degree of finish. It is available in limited quantity and is sold chiefly to hotels, restaurants, and clubs. The largest volume regularly available on the retail market consists of choice and good grades. Commercial beef represents a smaller volume and is generally more plentiful in the fall of the year. Utility, cutter, and canner grades are used chiefly in processed meat and meat products.

There are six grades of veal: prime, choice, good, commercial, utility, and cull; five grades for each of lamb and yearling mutton: prime, choice, good, utility, and cull; four grades of mutton: choice, good, utility, and cull.

The higher grades of meat have a higher fat content and thus a lower percentage of protein. The retail prices of meat cuts are not determined by their nutritive value but by other considerations, such as relative supply, tenderness, flavor, grain, color, general appearance and convenience of cooking.

Meat Inspection

In accordance with the Federal Meat Inspection Act of 1906, all meat packers engaged in interstate commerce are required to operate under the provisions of Federal Meat Inspection. There were about 1000 federally inspected meat packing plants in the United States in 1950. The purpose of inspection is to insure a clean, wholesome, disease-free meat supply that is without adulteration and is correctly labeled. Inspection includes the layout and construction of the slaughtering and processing facilities, ante-mortem and post-mortem inspection of the animals, condemnation and destruction of unfit materials, and continued inspection of the facilities and products throughout processing. Packers engaged only in intrastate

commerce are not required to operate under federal inspection. They are required to operate only under the provisions of the state and municipal inspection laws.

TABLE 18-2. WORLD PRODUCTION AND PER CAPITA CONSUMPTION OF MEAT
IN SPECIFIED COUNTRIES
(Carcass Meat Basis)

Countries	Total production, millions of pounds		Per capita consumption, pounds	
	Average 1946-50	1953	Average 1946-50	1953
<i>North America</i>				
Canada.....	2,053	1,985	129	135
Mexico.....	1,035	1,096	41	38
United States.....	22,264	24,795	151	154
Cuba.....	414	410	85	69
<i>Europe</i>				
Austria*.....	407	661	64	92
Belgium.....	559	815	85	94
Denmark.....	884	1,271	126	175
Finland.....	220	278	57	67
France.....	3,820	4,762	94	111
Germany, western†.....	2,700	4,665	61	98
Greece.....	161	190	25	26
Ireland.....	327	454	92	103
Italy.....	1,216	1,692	28	37
Netherlands.....	555	1,052	60	96
Norway.....	193	222	63	65
Portugal.....	324	305	40	35
Sweden.....	637	711	97	101
Switzerland.....	336	446	79	93
United Kingdom.....	2,025	3,003	101	122
<i>South America</i>				
Argentina.....	5,215	4,235	239	191
Brazil‡.....	2,695	3,000	52	54
Chile.....	426	422	74	69
Paraguay.....	230	170	147	114
Uruguay.....	743	816	219	248
<i>Africa</i>				
Union of South Africa.....	917	1,040	78	80
<i>Oceania</i>				
Australia.....	2,137	2,591	212	215
New Zealand§.....	1,201	1,241	228	186

* Includes some game, rabbit, and poultry.

† Averages for years 1948-50.

‡ Includes farm production and consumption.

§ Production data for years ending September 30.

Structure and Composition

The lean of skeletal meat consists chiefly of striated muscle tissue. The muscle is composed of bundles of muscle fibers held together by connective tissue. The muscle fiber (diameter 10 to 100 μ) is a complex system consisting of a large number of myofibrils (about 1 μ in diameter) imbedded in a matrix of viscous undifferentiated protoplasm called sarcoplasm and arranged parallel to each other and the fiber axis. The muscle fiber is surrounded by a thin sheath (less than 0.1 μ thick), the sarcolemma. The sarcolemma appears to be a structureless membrane and not collagenous in nature. The muscle fiber is formed from cells which merge at an early stage in its development. It consists of a collection of merged cells (syncytium).

Muscle proteins have been classified into two groups, the plasma and the stroma. The globulin myosin is the chief constituent of the fibrils, and globulin X and the albumin-like myogen, the principal constituents of the sarcoplasm. The following percentages have been reported for white muscle: myogen, 9 to 22; globulin X, 18 to 22; myosin, 39 to 57; and stroma, 16 to 17. Myosin may be extracted from muscle immediately after death by 0.3 *M* KCl + 0.15 *M* potassium phosphate at pH 6.5. A protein called actin is slowly extracted under the same conditions. Myosin combines with actin to yield actomyosin.

About 2 per cent of the fresh weight of muscle tissue consists of extractives of which 0.7 per cent is organic and 1.3 per cent, inorganic. The extractives contain free amino acids, creatine, creatinine, methyl guanidine, carnosine, inosine, glycogen, glucose, and lactic acid.

The proximate and mineral composition of typical cuts of meat and meat products are shown in Table 18-3; the vitamin content in Table 18-4, and the content of the ten essential amino acids in Table 18-5.

Meat is an excellent food source of iron. Beef, veal, pork and lamb contain from 2.2 to 3.8 mg of iron per 100 g of edible portion. Liver, tongue and kidney are among the richest food sources of iron. Meats are a fair source of phosphorus, containing from 130 to 200 mg per 100 g. Meat contains significant amounts of the nutritionally significant minor elements. The following are typical values for copper in milligrams per kilogram of fresh weight: pork, 3.1; beef, 0.8 to 1.2; lamb, 4.2; veal, 2.5; beef liver, 21.5. For manganese in milligrams per kilogram of dry weight: beef, .65; beef liver, 15; pork, 1.6; and veal, 1.3. The zinc content of lean meat varies from 26 to 50 mg, and of liver from 80 to 120 mg/kg.

The importance of meat in the diet in the United States is illustrated by the following percentages of the total nutrients in the diet contributed by meat: niacin, 41; protein, 28; thiamin, 25; iron, 23; fat, 22; riboflavin, 16; and calories, 12.

TABLE 18-3. PROXIMATE AND MINERAL COMPOSITION OF TYPICAL MEAT CUTS AND MEAT PRODUCTS

Meat	Per cent				Mg/100 g			Calories/ 100 g
	H ₂ O	Protein	Fat	Ash	Calcium	Phos- phorus	Iron	
<i>Beef</i>								
Rib.....	59.0	17.4	23.0	0.8	10	149	2.6	282
Loin.....	57.0	17.4	25.0	0.8	10	134	2.5	296
Rump.....	55.0	16.2	28.0	0.8	9	131	2.4	322
Round.....	69.0	19.5	11.0	1.0	11	180	2.9	182
Chuck.....	65.0	18.6	16.0	0.9	11	167	2.8	224
Hamburger.....	55.0	16.0	28.0	0.8	9	128	2.4	321
Dried.....	48.0	34.3	6.3	11.6	20	404	5.1	203
Corned.....	54.2	15.8	25.0	5.0	9	125	2.4	293
<i>Pork</i>								
Loin or chops.....	58.0	16.4	25.0	0.9	10	186	2.5	296
Ham (fresh).....	53.0	15.2	31.0	0.8	9	168	2.3	344
Boston butt.....	60.0	16.6	23.0	0.8	10	179	2.5	274
Ham (cured and smoked).....	42.0	16.9	35.0	5.4	10	136	2.5	389
Bacon.....	20.0	9.1	65.0	4.3	13	108	0.8	630
Canadian bacon.....	56.0	22.1	15.0	6.2	13	210	3.3	231
<i>Lamb</i>								
Chops.....	51.9	14.9	32.4	0.8	9	138	2.2	356
Leg.....	63.7	18.0	17.5	0.9	10	213	2.7	235
Shoulder.....	58.3	15.6	25.3	0.8	9	155	2.3	295
<i>Veal</i>								
Loin.....	69.0	19.2	11.0	1.0	11	207	2.9	175
Round.....	70.0	19.5	9.0	1.0	11	200	2.9	164
Shoulder.....	70.0	19.4	10.0	1.0	11	199	2.9	173
<i>Variety meats</i>								
Beef brains.....	78.0	10.4	8.6	1.4	16	330	3.6	125
Beef heart.....	77.0	16.9	3.7	1.1	9	203	4.6	108
Beef kidney.....	75.0	15.0	8.1	1.1	9	221	7.9	141
Beef liver.....	70.0	20.0	3.5	1.4	7	358	6.6	136
Beef tongue.....	68.0	16.4	15.0	0.9	8	199	6.9	—
<i>Meat products</i>								
Pork sausage, fresh....	41.9	10.8	44.8	2.1	6	100	1.6	450
Frankfurters.....	60.0	14.2	20.5	2.7	8	100	1.5	257
Bologna.....	62.0	14.8	15.9	3.3	9	112	2.2	221

Post-mortem Changes in Composition

The resting muscle usually is nearly neutral in reaction and contains about 1.0 per cent of glycogen. In the living tissue the energy for muscle contraction is believed to arise from the breakdown of creatine phosphate to creatine and inorganic phosphate. When creatine phosphate is broken down, adenosine triphosphate is formed as an intermediate in the formation

TABLE 18-4. VITAMIN CONTENT OF MEATS AND VARIETY MEATS

Meat	Milligrams per 100 grams fresh weight						Mcg/100 g, biotin	I.U./100 g, vitamin A
	Thiamin	Niacin	Ribo-flavin	Panto-thenic acid	Vitamin B ₆	Choline		
<i>Beef</i>								
Round.....	0.173	5.72	0.155	0.47	0.37	68	4.6	41,000
Tongue.....	0.16	3.90	0.28	2.00	0.13	108	3.3	
Liver.....	0.23	13.50	3.39	6.60	0.71	510	101.3	
Kidney.....	0.38	5.80	2.78	4.05	0.39	262	92.3	
Heart.....	0.40	8.20	0.88	1.75	0.29	170	7.3	
Brain.....	0.25	6.00	0.26	3.60	0.16	410	6.1	
<i>Pork</i>								
Ham (fresh).....	1.13	3.50	0.21	1.65	0.58	120	5.2	
Heart.....	0.37	6.05	1.19	2.10	0.35	231	18.2	
Liver.....	0.56	14.48	2.85	5.40	0.33	552	86.8	
Kidney.....	0.52	10.00	2.00	3.30	0.55	286	129.9	
<i>Lamb</i>								
Leg.....	0.20	6.30	0.30	1.30	0.28	83	5.9	26,000
Liver.....	0.41	13.00	3.50	6.90	0.37	360	127.0	

of adenylic acid. The formation of adenylic acid from adenosine triphosphate yields energy for muscle contraction. The conversion of glycogen to lactic acid supplies energy for resynthesis of creatine phosphate. Under aerobic conditions when the living tissues receive a good blood supply, the end products are probably CO₂ and water, rather than lactic acid. Several substances formed in the breakdown of glycogen can rehabilitate adenosine triphosphate. The first step in the breakdown of glycogen is the formation of hexose monophosphate. Thus, the breakdown of glycogen is dependent upon the presence of free phosphate.

The muscle protein, myosin (or an enzyme so closely associated with it that removal has been impossible thus far), is effective in breaking down adenosine triphosphate. The energy arising from the reaction is believed to be needed for maintenance of life in the muscle. The level of activity found post-mortem is related to the level of resting metabolism existing in the muscle before the animal is slaughtered. If the muscles are inert with a good oxygen supply for a considerable period before death, metabolism will be aerobic, and the lactic acid content will be very low. The pH of the muscle with no lactic acid or with a very low amount of it present is about 7.4. When blood circulation ceases at death, the production of lactic acid brings about a decrease in pH. The production of 1 per cent of lactic acid will lower the pH about 1.8 units. With a glycogen content of 1 per cent and subsequent lactic acid formation of 1.1 per cent, the pH reached at full rigor is about 5.6. This change in pH changes the physical state of the

TABLE 18-5. AMINO ACID CONTENT OF MEATS AND VARIETY MEATS
(Expressed in per cent of the protein)

Meat	Leucine	Valine	Iso-leucine	Threonine	Phenyl-alanine	Arginine	Histidine	Lysine	Methionine	Tryptophan
<i>Beef</i>										
Rib (choice)...	8.49	5.48	5.27	4.18	4.02	7.17	3.22	8.83	2.40	1.14
Round.....	8.89	5.49	5.18	4.55	4.34	6.07	3.68	9.22	2.50	1.21
Tongue.....	8.51	5.28	4.87	4.43	4.22	6.50	2.57	8.65	2.26	1.10
Liver.....	9.44	6.46	4.73	4.32	5.22	5.85	2.64	7.44	2.23	1.50
Kidney.....	8.90	5.96	4.47	4.50	4.96	6.08	2.56	7.32	2.09	1.39
Heart.....	9.19	5.38	4.81	4.50	4.49	6.41	2.65	8.30	2.38	1.26
Brain.....	8.51	5.52	4.48	4.68	5.44	6.04	2.60	6.70	2.10	1.36
<i>Pork</i>										
Ham (fresh)...	7.16	4.81	4.82	4.80	3.86	5.85	2.72	7.98	2.58	1.33
Loin.....	6.97	5.16	4.82	4.78	3.83	6.95	2.59	7.88	2.48	1.30
Heart.....	9.07	5.67	4.86	4.63	4.44	6.71	2.60	8.23	2.36	1.26
Liver.....	9.57	6.42	5.22	4.42	5.43	6.11	2.79	7.13	2.18	1.47
Kidney.....	8.59	5.96	4.72	4.39	4.62	6.38	2.58	6.82	2.11	1.41
<i>Lamb</i>										
Leg.....	7.15	4.74	4.60	4.79	3.72	6.81	2.55	7.67	2.50	1.31
Liver.....	9.01	6.49	4.45	4.58	5.58	5.96	2.72	7.32	2.07	1.42

muscle, especially the protein myosin. There results a change in color, an increased ease in expression of juice and penetration of salts into the tissue, and a decrease in electrical resistance. These changes have been attributed to the shrinkage of the muscle fibrils as the isoelectric point (pH 5.3 to 5.5) of the protein myosin is approached. However, when sufficient acid is produced, rigor mortis may set in at a pH of 6.3. The enzyme, adenosine triphosphatase, which splits inorganic phosphate from adenosine triphosphate, is more active at pH 6.5 and lower. Thus, removal of adenosine triphosphate appears to be the immediate cause of rigor.

At or slightly below pH 5.4, the glycolytic system is inactivated. If glycogen is still present and alkali is added to raise the pH, glycolysis is resumed. Enough glycogen to reach pH 5.4 is seldom present in the tissues. The pH reached at full rigor is determined by the amount of glycogen present. A high pH associated with low glycogen is detrimental to color, texture, and keeping quality of meat. Exercise of the animal decreases the glycogen content. If the work is light and nutrients are available, glycogen is replenished. Strenuous exercise may completely deplete the glycogen content of the muscles. With alternate periods of exercise and rest, the level of glycogen may be raised.

Ante-mortem feeding of sugar to swine and beef cattle increases the weight of the liver and the amount of glycogen in the liver and muscles. When sugar was fed, the pH of swine muscle tissue was decreased from

pH 6.0 and 6.6 to a pH of 5.3. An improvement in texture and flavor of liver and in keeping time of fresh pork and beef has been found when sugar is fed ante-mortem.

The pH of beef in full rigor usually ranges from 5.4 to 6.0. Higher or lower values may be found occasionally. The pH of pork may vary from 5.4 to 6.7.

Dark-cutting Beef

The color of the lean beef tissue is due to the myoglobin content of the muscles. When myoglobin is oxygenated, the meat has a bright red color, and when it is non-oxygenated, a dark color. At high pH values the color is darker. When the beef muscle is cut, the surface has a purple color because the myoglobin is non-oxygenated. After a few minutes exposure to air, the myoglobin takes up oxygen and the meat becomes bright red in color.

A small percentage of beef carcasses are found to be "dark-cutting." When the muscles of "dark-cutting" carcasses are cut and exposed to air, they remain dark purple in color instead of becoming bright red. Although dark-cutting beef is not inferior to light-cutting beef in appearance, palatability, and nutritive value, the retail trade and consumer discriminate against it.

In dark-cutting beef, oxygen uptake is retarded greatly. Dark-cutting beef has a higher pH, lower glycogen and reducing sugar content, lower oxidation-reduction potential, and greater oxygen uptake than light-cutting beef. Dark-cutting beef may be produced experimentally by lowering the muscle sugar content with large doses of insulin. The incidence of dark-cutting beef may be lowered by avoidance of exposing the animals to chill and by providing good housing and adequate feed and water prior to slaughter.

Aging of Beef

Following slaughter, beef is held under refrigeration for varying lengths of time. During this storage period certain physical and chemical changes occur in the meat which improve its palatability. This process is called aging or ripening. Large quantities of beef are retailed within 5 to 10 days after slaughter and are aged only incidentally in the course of their storage and distribution to the consumer. The highest grades of beef may be aged at 32 to 38°F for from 4 to 6 weeks. Aging at higher temperatures is not feasible unless special means are provided to retard growth of microorganisms. In the Tenderay process ultraviolet rays are used to retard growth of microorganisms, and aging is carried out at 65 to 68°F for 48 hours.

The chief purpose of aging beef is to increase tenderness. Several types of instruments have been devised to measure the tenderness of meat. To

be of value the results of any mechanical or physical tests must necessarily be related to the results of human organoleptic tests on the samples. In this country the Warner-Bratzler instrument has been used most extensively. On cooked beef a good correlation has been found between the human test panels and the Warner-Bratzler shear test but not with uncooked beef.

The precise chemical and physical changes that are responsible for the increase in tenderness occurring during aging are not known. Earlier it was believed that the connective tissue was largely responsible for lack of tenderness. Studies on changes in the connective tissue during aging have failed to account for changes in tenderness. More recently the evidence indicates that increased tenderness resulting from aging may be due to changes occurring in the muscle fibers. The chemical nature of such changes is not known. Among the proteins occurring in muscle there are a number which can function as enzymes, but during rigor their substrates are largely exhausted. Those enzymes which remain active are chiefly proteolytic. During aging there is an increase in non-coagulable nitrogen and in sulfhydryl groups. But the increase in non-coagulable nitrogen represents only about 2 per cent of the total protein after 30 days of aging. Thus it does not seem probable that these changes would be significant to account for the increase in tenderness. They may have some effect on the changes in flavor occurring during aging of beef.

Curing of Meats

The curing of meats had its origin in prehistoric times. The original purpose was to preserve meat without refrigeration. The chief ingredient in preservation was salt. From time to time various modifications and additions were made in the curing ingredients. Today the curing ingredients, in addition to salt, may include sodium nitrate and/or sodium nitrite, sugar, phosphates, and spices. The cured products may or may not subsequently be smoked and/or partially dried. With modern refrigeration, today there is no longer need for a high salt content as a preservative. Salt is used in smaller amounts and in most cases largely for its effect on flavor. The modern mild-cured products are made possible by rigid sanitation and thorough refrigeration during processing. They require refrigeration for preservation.

Curing is generally restricted to pork and beef. Cured meats are constituted largely of such cuts as hams, picnics, bellies (bacon), thigh muscles (dried beef), brisket (beef), and ground or comminuted meats. Some of the cured products, such as bacon, ham, shoulder and sausages, are smoked following curing. Cured comminuted meats are processed into sausage or canned.

The Federal Meat Inspection Branch permits the following ingredients

to be used in curing meats: salt, sodium nitrate, sodium nitrite, sugar, vinegar, and the following in certain products: disodium phosphate, sodium hexametaphosphate, sodium tripolyphosphate, and sodium pyrophosphate. Salt serves chiefly as a preservative and flavoring agent. Sodium nitrate and sodium nitrite serve primarily as color developing agents, although they may have some bacteriostatic effect. Sugar is used because it assists in stabilizing the cured color by contributing to the maintenance of reducing conditions in the meat, and also for its effect on flavor.

The chief pigments of meat are the conjugated proteins myoglobin (a constituent of the muscle tissue) and hemoglobin from traces of blood remaining in the tissues. Myoglobin combines with molecular oxygen to form oxymyoglobin. The reaction is reversible and may be regarded as "oxygenation" rather than oxidation since the iron of the heme portion of the myoglobin remains in the ferrous state when myoglobin is "oxygenated." Due to exposure to oxygen of the air the pigment on the surface of meat is oxymyoglobin. In the interior of meat the pigment is present in the unoxygenated state, since the oxygen is depleted in other oxidative processes. Unoxygenated myoglobin is purple and oxymyoglobin red in color. When fresh meat is cooked the protein is coagulated and the hematin becomes brown, the color of fresh cooked meat. Meats cured with nitrite become bright red in color. When cooked they retain their red color.

The red or pink color of cured meats is due to the formation of nitric oxide myoglobin through reaction of nitric oxide with myoglobin. An acid reaction and reducing conditions are necessary for proper development of the cured color. At the usual pH of meat (5.5 to 6.5), sodium nitrite decomposes to yield nitric oxide. Nitric oxide combines with myoglobin to give nitric oxide myoglobin. Under more acid conditions the pigment may be oxidized to metmyoglobin with a brown undesirable color. The iron of metmyoglobin is in the oxidized or ferric form. When heated the nitric oxide myoglobin of cured meats is denatured to form nitric oxide hemochromogen which has a bright red or pink color. The range of nitrite concentration that yields satisfactory curing is rather narrow. Color fixation and stability of the color is poor if insufficient nitrite is present. The color may be brown if too much nitrite is present.

For proper color development meat must be depleted of oxygen so that the myoglobin is in the non-oxygenated state. The cured meat pigments are very labile to oxygen and sensitive to light. Light promotes fading of the cured meat pigments. Reducing conditions during curing and following color fixation favor good development and retention of color. Reducing sugars, perhaps as a result of bacterial action, help to maintain reducing conditions. Figure 18-1 illustrates the color changes occurring in the curing and storage of meats.

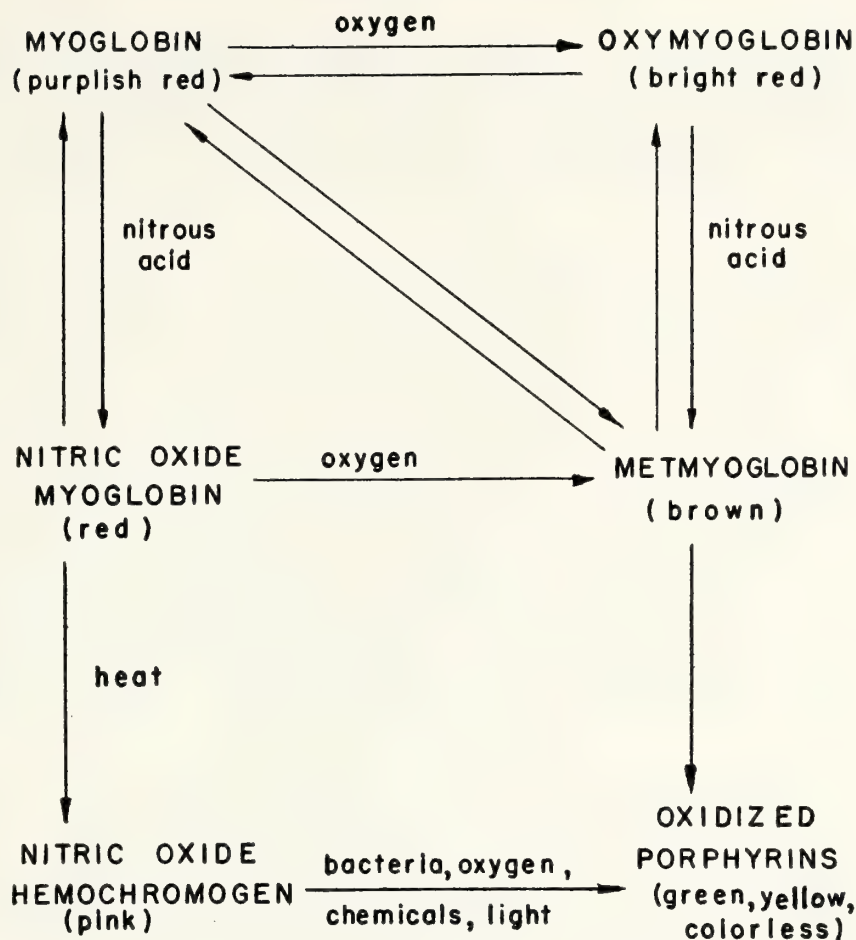


Figure 18-1. Color changes commonly observed during the curing and handling of meats. (From Circular 2 American Meat Institute Foundation.)

Certain nonpathogenic bacteria can convert the red color of cured meats to a pale green color. Most of these bacteria belong to the lactic acid group. They have certain characteristics that enable them to grow vigorously on cured meats. They are very heat-resistant for nonspore formers, are relatively salt-tolerant, and have certain nutritional requirements that enable them to grow well on sausages and cured meats. They can grow just as readily in the interior as on the surface of meat, but greening occurs only in the presence of oxygen. Several types of discoloration occur depending upon the stage of manufacture when contamination occurs. Contamination and growth on the surface result in surface greenish patches of irregular size and shape. If processing temperatures are not high enough to kill all of the bacteria in the center core of the sausage, subsequent growth and multiplication of the bacteria may result in the development of a green core several hours after the cut surface is exposed to air. These bacteria are able to oxidize certain substances in the sausage with the production of hydrogen peroxide. The hydrogen peroxide oxidizes the pink colored nitric oxide hemochromogen to a series of green, yellow, or colorless compounds.

Curing is carried out in a refrigerated room at about 38°F. The rate of penetration and diffusion of curing ingredients throughout the meat in-

crease with rise in temperature; but when the process requires a number of days, there is danger of spoilage if the temperature is too high. Various types of containers, such as racks, tierces, vats, concrete vats, and metal or wooden boxes, are used depending upon the type of product and cure used.

Two general methods of curing are used: pickle and dry cure. Hams, butts, and picnics are usually pickle-cured while bellies are either dry or pickle-cured. Some of the clear bellies and heavy ribs are dry-salted. For export, hams, bellies and Wiltshire sides are either sweet-pickled or dry-salt-cured.

Pickle Curing. Hams are usually pumped with pickle before being placed in the cover pickle in the curing vat. Diffusion of the curing ingredient throughout the ham is hastened by injecting pickle solution into the ham. For short cures, hams and shoulders are generally artery or stitch pumped. In artery pumping, about eight to ten per cent of pumping pickle is forced into the arterial system by inserting the needle into the exposed end of the artery. In stitch pumping, the needle has a number of holes through which the brine enters the meat. Typical curing mixtures are shown in Table 18-6.

After pumping, the hams are placed in tierces or vats and covered with pickle. From 4.5 to 5.5 gal of cover pickle is used for each 100 lb of meat. The length of cure varies greatly and may range from three to one-half day per pound.

Dry Curing. Bacon is one of the most important cuts cured by the dry-curing method. About 5 lb of the curing mixture is used for each 100 lb of fresh bellies. The curing ingredients must be mixed uniformly. After the bellies are rubbed with the dry curing mixture, they are placed in a box, meat side up. Each layer of bellies is sprinkled with the proportionate amount of the curing mixture. Spaces left in the box, due to uneven sizes of bellies, are filled with fat backs, jowl butts, or briskets. The top layer is laid with the skin side up. The lid of the box is clamped tightly after packing to force out pickle so that it covers the meat. The curing period varies but generally is about three days per pound of average belly. The pro-

TABLE 18-6. TYPICAL CURING MIXTURES FOR HAMS

	Mixed cure		Nitrate cure		Nitrite cure	
	Pump pickle	Cover pickle	Pump pickle	Cover pickle	Pump pickle	Cover pickle
Sugar, lb/100 gal.	20	10	20	10	20	10
Sodium nitrate, lb/100 gal.	1	2	8	4	—	—
Sodium nitrite, lb/100 gal	1½	1	—	—	1½	1
Salometer	90°	70°	90°	75°	90°	75°

cedures used may vary considerably. Bellies may be cured in open vats, or dry cured for a short period and then pickled cured. Hams and butts are dry cured to a limited extent for special purposes. The following is a typical formula for dry-curing of bacon:

Salt (lb)	3
Cane sugar (lb)	2¼
Sodium nitrite (oz)	¼
Sodium nitrate (oz)	2

About 5 lb is used for 100 lb of fresh bellies.

Injecto-Cure. In this method, the pickle is forced into the belly under pressure by machines that have approximately 100 needles. The needles are arranged to give uniform coverage and distribution of the mixture into the belly. The bellies are injected with from 9 to 10 per cent of their weight of pickle. The bellies may then be placed on racks and held under refrigeration for 24 to 48 hrs, or they may be placed in cover pickle for several days.

Comminuted Meats. The curing ingredients are mixed thoroughly with finely ground or chopped meats. The curing ingredients are distributed rapidly throughout the meat. The products may be held under refrigeration for a few hours or several days to permit the curing reaction to take place. The process may be speeded up with heat as in canning when the "hot cure" method is used.

Smoking of Meats

Following curing, meat may be smoked or cooked without smoking. When cured meats are removed from the curing vats, there may be an excess of curing salts on the surface. The concentration of curing ingredients in the parts of the ham nearer the surface may be higher than in the center of the piece of meat. To remove the excess curing ingredients, the meat may be soaked and washed, or in some cases only washed before smoking. Several different types of soaking vats are used. Frequently wooden vats with racks 6 to 10 in. above the bottom are used. The vats keep the meat above the water which accumulates at the bottom of the vat and also permit circulation of the water. Circulation is accomplished with air jets directed towards the bottom of the vat. After being thoroughly soaked, the meat is washed with water at 110°F. High-pressure spray washers have been adapted for washing cured meats.

Two types of smokehouses are used: the older natural air-circulation type, which requires the height of at least three floors to operate efficiently; and the more modern so-called "air-conditioned" type. The air-conditioned, single-story, insulated smokehouses are well suited for processing the tendered and the ready-to-eat smoked meats.

Different methods are used to generate the smoke from hardwood saw-

dust. Cord wood heated to embers may be smudged with sawdust, or a gas or oil flame may be directed against a pile of sawdust to generate the smoke. Hickory sawdust is preferred but other hardwoods, like oak, maple or birch, may be used. Careful control of the air temperature, humidity, and movement is important.

Long-cured meats are generally smoked at lower temperatures than the quick cured meats. With long-cured meats, the temperature of the house may be raised rapidly to 135°F and maintained at that temperature until the internal temperature of the meat has reached at least 110°F. Since the color of cured meat is fixed more permanently at higher temperatures, bacon and some long-cured hams may be smoked to internal temperatures of 125 to 128°F. When these temperatures are reached, the temperature of the smokehouse is lowered to 120–122°F. Bellies may be smoked from 18 to 24 hr and hams from 20 to 26 hr. Tendered cook-before-eating and ready-to-eat smoked meats must be heated to an internal temperature of not less than 137°F in order to destroy trichina (Federal Meat Inspection Branch regulations). The increased tenderness of present day mild-cured hams is due to the slow cooking process occurring during the smoking at higher temperatures. Regulations of the Federal Meat Inspection Branch do not permit the use of enzymes to tenderize hams. The regulations also prohibit the use of so-called “liquid smokes,” such as liquids containing pyroligneous acid or similar products, of salt containing the products of wood distillation, or of coloring matters which may impart a smoke color to meats.

Freezing of Meat

Meat may be stored for many months by freezing and holding at low temperatures. Changes in structure and physical properties of meat occur when it is frozen and then thawed. When meat is frozen rapidly at low temperatures, the ice crystals are small and are formed within the meat fibers. When frozen slowly, the water moves into the interfiber spaces and forms ice crystals. The rate of freezing is dependent upon the temperature, size of piece of meat, and the rate of removal of heat by the medium in contact with the meat. When thawed, the drip loss of quick frozen meat is generally less than that of slow-frozen meat. If quick frozen meat is held in storage under conditions which permit the growth in size of the ice crystals, the advantages of quick freezing are lost.

The following are among the most important factors affecting drip-loss: kind of meat, the length of aging, pH of the meat, temperature and length of time of storage, the amount of cut surface, and the rate of thawing.

The amount of packaged frozen meat cuts sold in retail market has been increasing in recent years. Considerable quantities are stored by consumers

in home freezers and rented lockers in locker plants. Fresh beef retains good quality for a year or more, and pork for six months if properly packaged and held from 0 to -10°F . The cuts should be tightly wrapped with material of low moisture-vapor transmission. Cured meats do not keep well when frozen.

Large quantities of four-way frozen boneless beef are purchased by the U. S. Armed Forces. Four divisions of cuts are made, as follows: roasts or steaks (dry heat cooking), roasts or steaks (moist heat cooking), diced beef, and ground beef. Each cut of the roasts or steaks is wrapped individually and tightly in waxed paper. Approximately 45 lb of the cuts is packed in a box. The diced and ground meat are packed in boxes of about 50 lb. The boneless beef is placed in a sharp freezer or in a wind tunnel and frozen at 0°F , or lower. The meat is then stored at 0°F , or lower.

The freezing of halves or quarters of the beef carcass has not proved very satisfactory because of their slow rate of freezing. From 48 to 96 hr may be required to reach the temperature of 0°F in the deepest part of the carcass. Considerable quantities of frozen beef is shipped from South American countries and from Australia to England. However, the best grades are preferably shipped as chilled beef. Frozen mutton and lamb are shipped in large quantity from Australia and New Zealand to England. The carcasses are encased in moisture-vapor-proof paper or latex bags.

Sausage, Ready-to-serve and Canned Meats

Large quantities of prepared meat products are produced including many kinds of sausages, meat loaves and canned meats. It has been reported that sausages were made by the Babylonians as early as 1500 B.C. Historical records show that sausages were prepared in the ninth century B.C.

The sausages prepared in this country can be classified into six groups, as follows:

(1) Fresh sausage made from uncured meat. The product is not cooked. (Fresh pork sausage, fresh sausage, fresh thuringer style sausage, Bratwurst.)

(2) Smoked sausage made from uncured meat. The product may be sold uncooked or cooked. (Smoked pork sausage, Polish sausage, frankfurters, weiners, bologna, etc.)

(3) Cooked sausages which are usually made from uncured meat. If smoked, they are smoked following cooking. (Liversausage, blood sausage, and tongue.)

(4) Cooked specialties usually made from uncured meats. (Various types of meat loaves, luncheon meats, head cheese, etc.)

(5) New condition sausage made from fresh meat, curing ingredients and

spices. After curing 48 hr, the meat is placed in casings and cooked in the smokehouse at high temperatures. The product is subsequently air dried. (Cooked salami, thuringer cervelat, etc.)

(6) Dry sausage made from fresh meat, curing ingredients and spices. It is cured for 2 or 3 days. The meat is placed in casings and dried slowly for a long period. (Summer sausage, various cervelats, Italian salami, etc.)

The purpose of canning is to destroy bacteria which may cause spoilage and thus to increase the period of time the product may be held in storage. The temperature and time of processing required to secure commercial sterilization depends upon a number of factors as, for example, the quality and consistency of the product, the size and shape of the container, the type of retort and the initial temperature of the product. Processing schedules are devised after careful study of the various factors for each set of conditions encountered in commercial operations. Some items, like whole boneless canned hams and six-pound cans of luncheon meat, are not processed sufficiently to be commercially sterilized. These products are kept under refrigeration.

A large range of different meats and meat products are canned. The following are among the most important items canned: chopped spiced luncheon meat, chopped spiced ham, roast beef, corned beef, corned beef hash, whole, half and quarter hams, sausages, sliced bacon, vinegar pickle products (like pig's feet), pork and beans, chili con carne, soups, stews, etc. Table 18-7 shows the production of sausage and canned meat under federal inspection for the year 1953. Table 18-8 gives the proximate composition and vitamin content of typical prepared and canned meats.

Dehydration of Meat

A large quantity of dehydrated meat was produced during World War II for lend-lease purposes. Dehydration made possible a saving in shipping space, tin and strategic metals. By compressing the dehydrated product, it is possible to reduce the shipping space to one-third that required for shipment of frozen boneless beef.

TABLE 18-7. PRODUCTION OF FEDERALLY INSPECTED SAUSAGES AND CANNED MEAT IN THE UNITED STATES IN 1953

Type	Millions of pounds
<i>Sausages</i>	
Fresh products.....	204.0
Dried or semidried.....	124.3
Wieners and frankfurters.....	540.8
Other smoked or cooked sausage.....	610.8
Total sausage.....	1,479.9
<i>Canned product</i>	
(For civilian and Department of Defense use).....	2,026.3

TABLE 18-8. PROXIMATE COMPOSITION AND VITAMIN CONTENT OF PREPARED MEATS

Product	Protein	Fat	Moisture	Thiamin	Ribo- flavin	Niacin
	(%)	(%)	(%)	mg/100 g	mg/100 g	mg/100 g
<i>Sausage (cured)</i>						
Thuringer (beef and pork)	16.88	24.25	49.38	0.117	0.239	4.18
Cooked salami (beef and pork)	17.19	20.94	52.56	0.179	0.204	3.75
Bologna (beef and pork)	13.38	19.46	59.42	0.109	0.226	2.67
Pork sausage (smoked)	14.98	32.30	50.60	0.269	0.230	3.49
Sausage smoked (beef, veal, pork)	14.49	32.25	46.10	0.221	0.192	3.09
Dutch loaf (beef and pork)	14.31	14.39	58.35	0.308	0.171	3.15
Head cheese	14.56	19.04	59.04	0.029	0.097	0.53
Braunschweiger	12.96	31.72	46.46	0.128	1.41	8.08
<i>Canned products</i>						
Veal loaf (veal and pork)	17.30	15.38	60.68	0.026	0.186	3.56
Luncheon meat spiced (pork)	12.56	29.45	50.27	0.330	0.156	2.56
Ham chopped (cured)	16.63	16.70	60.34	0.323	0.174	3.36
Pork chopped (cured shoulder and ham)	14.20	26.37	54.56	0.244	0.211	2.45
Vienna sausage (beef and pork)	12.39	16.82	68.00	0.038	0.164	2.73
Potted meat (beef, tripe, heart)	16.08	16.32	65.20	0.027	0.225	1.22
Beef chopped (cured)	16.54	16.22	62.82	0.017	0.150	4.92
Beef diced	20.84	3.10	75.23	0.023	0.202	4.99
Veal diced	21.00	1.25	76.70	0.029	0.305	6.73
Pork diced	21.09	5.68	71.76	0.203	0.250	4.66

Pork, beef and mutton were dehydrated successfully on a commercial scale. The meat is first cut into pieces about 2 in. in diameter. After cooking in a steam-jacketed kettle for 30 min. at 165–175°F, the meat is passed through a meat chopper equipped with $\frac{1}{8}$ to $\frac{1}{4}$ in. plates. The product is then dried in a rotary air dryer or a tunnel-type dryer to a moisture content of not more than 10 per cent. The product is suitable for use in meat loaves, patties, croquettes, soups and similar products. Larger pieces of meat, like steaks and chops, have been dried under vacuum in the frozen state. By using this technique, dehydrated steaks and chops have been produced which reconstitute readily when placed in water. The rehydrated steaks and chops are comparable to the fresh product. These products have not been produced on a commercial scale.

By-products

The returns from the sale of by-products constitute an important part of the total value of the products obtained from the slaughter of animals. Usually from 76 to 89 per cent of the total sales value of the products are derived from the sale of the carcass. Edible fats, inedible products and variety meats account for the remainder. Inedible products account for

TABLE 18-9. COMMERCIAL PRODUCTION OF ANIMAL FATS IN THE UNITED STATES
1949-1953*

	(In millions of pounds)				
	1949	1950	1951	1952	1953
Lard.....	2,184	2,294	2,531	2,612	2,123
Edible beef fats					
Tallow.....	105.6	108.3	89.2	123.5	174.6
Stearine.....	31.4	34.0	29.0	23.9	26.5
Oleo oil.....	49.9	58.9	46.3	45.5	55.6
Inedible tallow and grease.....	1,861.4	1,909.7	1,922.0	2,061.3	2,289.3

* Source: U. S. Bureau of the Census. Facts for Industry—Animal and Vegetable Fats and Oils, 1952 and 1953.

from 2.0 to 18.5 per cent. The following are among the most important by-products: hides, skins, lard, edible tallow, inedible grease and tallow, animal protein feeds, hair, wool, dried blood, bone, glue, gelatin, casings, sutures, tennis strings and pharmaceuticals. The efficient utilization of by-products enables the packer to pay more for the livestock than if the price is determined solely by the price the consumer is willing and able to pay for the edible products. The wholesale price of the beef carcass is usually less than the cost of the live animal.

Meat Food Fats

Table 18-9 shows the quantity of edible and inedible animal fats produced commercially in the United States for the years 1949-53. Lard and edible beef fats represent one of the most important by-products of the meat packing industry. Annual commercial production is approximately 2,750,000,000 lb. This amount does not include the 400,000,000 lb of lard produced annually in farm slaughter of swine.

Lard

Four methods are used in rendering lard: (1) steam rendering, (2) dry rendering, (3) open-kettle rendering, and (4) drip rendering.

In steam rendering, the raw materials are rendered in a cylindrical steel tank with steam under pressure. Cooking is carried out in direct contact with steam at pressures from 40 to 60 lb. The time of cooking varies from 2 to 6 hours. After cooking, the charge is allowed to settle for several hours. The lard is then drawn off to a settling tank where traces of moisture are removed by heating with a steam coil or jacket.

In dry rendering the materials are heated in a horizontal, steam-jacketed vessel equipped with a central rotating shaft to which arms are attached. Moisture is exhausted through an air vent or drawn off by vacuum and condenser. After cooking, the material is discharged into a tank with a

false perforated bottom. The lard drains through the perforated bottom and the cracklings are retained on the screen.

Fuller's earth and activated carbon are used to bleach and clarify lard. The clarifying agent is mixed with the lard in a bleaching tank and then passed through a filter press to remove the clarifying agent.

Lard is sold in either the smooth or grainy form. Smooth lard is plasticized either by precooling to 110°F and then passing over a chilled roll, or by passing the product through an internal chiller or plasticizer. Plasticizing lard helps to prevent it from separating into liquid and solid portions, and permits it to be held at higher temperatures without melting. Grainy lard is prepared by allowing it to cool slowly in the package or by chilling slowly in a large container and then transferring to the package.

Lard flakes (hydrogenated lard with a titer of 57–60°C) in amounts of 3 to 10 per cent may be added to lard to raise the melting point. When such lard is stabilized with a suitable antioxidant, it is not necessary to store it under refrigeration.

The Federal Meat Inspection Branch has approved a number of antioxidants for use in edible animal fats. These antioxidants are effective in retarding the development of oxidative rancidity of lard and tallow. Most of the antioxidants do not carry through, and retard development of rancidity in the foods prepared with lard as, for example, pastry, crackers and potato chips. Two of the antioxidants, butylated hydroxyanisole (BHA)—a mixture of 2 and 3-tert-butyl-4-methoxyphenol, and butylated hydroxytoluene (BHT)—2,6-di-tert-butyl-4-methyl phenol, are unusually effective in carry-through. BHA, in combination with propyl gallate and citric acid, is used extensively to stabilize lard and other animal fats.

When a shortening with less flavor and odor is desired, additional processing is needed. Lard or blends of lard and other animal fats are refined, bleached and deodorized. Lard flakes and a suitable antioxidant are added. Monoglycerides may be added to increase the emulsifying power. The product is plasticized and packaged in an attractive package. Special animal fat shortenings are prepared for industrial baking and deep fat frying. The recent development and commercial use of a process of transesterification in the treatment of animal fats have made it possible to produce shortenings of superior performance from animal fats.

Edible Beef Fats

Edible tallow is generally rendered by the open-kettle method. It is made from edible fats not suitable for production of oleo stock or from material otherwise used for oleo stock.

Oleo stock is prepared from the internal fatty tissues of cattle and sheep. The tissues are passed through a cutter and washed thoroughly, and are

TABLE 18-10. FATTY ACID COMPOSITION AND ANALYTICAL CONSTANTS OF ANIMAL FATS

Fatty acids	Lard (%)	Beef tallow (%)	Mutton tallow (%)
Saturated			
Lauric.....	Tr	0.1	—
Myristic.....	1.0	3.0	2.0
Palmitic.....	28.0	29.0	25.0
Stearic.....	13.0	20.0	30.0
Arachidic.....	—	—	0.8
Unsaturated			
Myristoleic.....	0.2	0.5	—
Palmitoleic.....	3.0	2.0	—
Oleic.....	46.0	42.0	39.0
Linoleic.....	6.0	2.0	4.0
Linolenic.....	0.7	0.5	—
Arachidonic.....	2.0	0.1	—
Analytical constants			
Iodine number (Wijs).....	53-77	40-48	35-46
Saponification value.....	190-202	190-199	192-197
Melting point (0°C).....	33-46	40-48	44-51
Titer (0°C).....	32-43	40-47	43-48

then chilled in water at 38°F. After draining, the fats are ground through 5/8 in. plates. The ground fatty tissues are rendered in a steam-jacketed kettle at 155°F. Salt is added to assist in the separation of the fat and water. The melted fat is centrifuged and chilled to 90°F. The stearin separates out in grainy form and is removed from the oil by pressing in canvas cloth.

The fatty acid composition and analytical constants of animal fats are given in Table 18-10.

Inedible Animal Fats

Inedible tallow and grease are obtained from the rendering of products not considered suitable for human food. Two methods of rendering are used: the older wet rendering and the newer dry rendering. The following average amounts of raw materials per animal are rendered for inedible fat: beef, 80 lb; sheep, 8 lb; calves, 15 lb; and hogs, 15 lb.

Table 18-11 gives the grades and standards used in the trade for tallows and greases. The chief use of tallow and grease is in soap manufacture. Considerable quantities are used for various other industrial purposes. The following are some of their other uses: cutting oils, lubricating wool before spinning, treatment of leather, in lubricating greases. Considerable quantities are converted to glycerine and fatty acids which are used for industrial purposes. Various chemicals produced from the fatty acids find a wide use in industry.

Recently large quantities of grease and tallow stabilized against oxidative rancidity with suitable antioxidants have been used as an ingredient in

TABLE 18-11. CHARACTERISTICS OF INEDIBLE GRADES OF ANIMAL FATS

Fats	Titer (minimum) (°C)	F.F.A. (maximum) (%)	M.I.U. (basis) (%)	F.A.C. color maximum untreated and unbleached
Tallows				
Fancy.....	41.5	4	1	7
Choice.....	41	5	1	9
Prime.....	40.5	6	1	13 or 11B
Special.....	40.5	10	1	19 or 11C
No. 1.....	40.5	15	2	33
No. 3.....	40.5	20	2	37
No. 2.....	40	35	2	No color
Greases				
Choice white.....	37	4	1	11
A, white.....	37	8	1	15
B, white.....	36	10	2	19 or 11C
Yellow.....	36	15	2	37
House.....	37.5	20	2	39
Brown.....	38	50	2	No color

animal feeds. It is estimated that currently these fats are being used in feeds at an annual rate of 200 to 250 million pounds.

Animal Protein Feeds

The residue obtained from the rendering of inedible animal fats is used as a protein supplement feed. Two products are produced: meat scrap and tankage. When the products contain more than 4.4 per cent phosphorus, they are called meat and bone scrap and tankage with bone, respectively. Meat scrap is made only by the dry rendered process and does not contain blood. Tankage may consist of either the wet rendered or dry rendered product, or a mixture of the two, and may contain blood. Dried blood (blood

TABLE 18-12. PER CENT OF AMINO ACIDS IN MEAT AND BONE SCRAP AND BLOOD MEAL

	Meat and bone scrap	Blood meal
Leucine.....	3.28	14.06
Valine.....	2.41	8.21
Isoleucine.....	1.48	0.90
Threonine.....	1.88	3.83
Phenylalanine.....	1.78	5.93
Arginine.....	3.90	3.64
Histidine.....	0.96	5.00
Lysine.....	2.84	6.30
Tryptophan.....	0.37	1.06
Methionine.....	0.71	1.16
Cystine.....	0.40	—
Glutamic acid.....	9.05	—
Tyrosine.....	1.08	2.33

meal) and steamed bone meal for feeding purposes are also produced by the meat packing industry.

Table 18-12 gives the amino acid content of meat and bone scrap and blood meal. The amino acid composition of tankage is similar to that of meat and bone scrap, except that the tryptophan content is higher.

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19. THE CHEMISTRY OF PLANTS

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Introduction

Browne's classical treatise on the history of agricultural chemistry reveals an intense interest in the composition of agricultural commodities as far back as 640 B.C. As new and improved analytical techniques have become available through the years, new inroads have been made in our knowledge of the chemistry of plants and the importance of plant constituents to the welfare of all members of the animal kingdom. Although food habits can change radically within a relatively short time, as indicated by the data in Table 19-1, even today large segments of the world's human population are dependent almost entirely upon agricultural crops as primary sources of food. It has been estimated that in China, as recently as 1945, over 95 per cent of the caloric intake of humans was obtained directly from agricultural crops compared with the United States in which only between 50 to 55 per cent of the calories were derived directly from plant products.

Studies on the chemistry of plant products have not progressed as rapidly as chemical studies in other fields, possibly because support for research on medical, nutritional, and technological problems has had greater apparent appeal and urgency. Fortunately basic studies in apparently unrelated fields of animal and microbiological research have contributed much to our knowledge of the chemistry and metabolism of plants through the realization that many biological processes are common to all living tissues. Recent progress in fundamental studies of intermediary metabolism, stimulated by Schoenheimer's, Krebs' and Lipmann's now classical investigations, lend credence to the hypothesis that apparently dormant biological systems are in a state of exceedingly rapid, but balanced chemical activity

TABLE 19-1. CHANGE IN FOOD HABITS AS MEASURED BY INCREASE IN U. S. ACREAGE BETWEEN 1919 AND 1939

Commodity	Increase (%)
Tomatoes	64
Celery	80
Citrus	106
Green peas	196
Kale	290
Asparagus	300
Green beans	310
Lettuce	475
Spinach	590
Carrots	745

now frequently referred to as "Dynamic Equilibrium" and which is illustrated diagrammatically in Figure 19-1. It may be seen from Figure 19-1 that acetyl-coenzyme A or "active acetyl," shown in Figure 19-2, appears to lie at the apex of a large number of metabolic processes. Although incomplete and partially speculative, the scheme of enzymatically catalyzed biochemical reactions, shown in Figure 19-1, presents reasonable mechanisms for many well-known chemical transformations in biological materials. The dynamic equilibrium concept furnishes a plausible physicochemical explanation of how rapid gross compositional changes can occur in living tissues. The hypothesis suggests that relatively small changes in the activity of a single enzyme system can effect an imbalance in a series of characteristically fast biochemical reactions, causing a rapid accumulation or depletion of metabolic substrates such as that which occurs during the germination of seeds and the maturation and deterioration of fruits. These new concepts of biological chemistry are being studied actively in many laboratories with both plant and animal systems. The unavailability of sufficient experimental data prevents the presentation of this section on the chemistry of plants in a manner consistent with contemporary hypotheses. However, current renewed interest and intensive fundamental studies on plant metabolism employing the elegant radioisotope (Table 19-2) and chromatography techniques, developed during the past few years, promise to extend considerably our knowledge of plant chemistry.

In the present section, compositional data on plant materials are presented on a moisture-free basis in an attempt to demonstrate chemical rather than nutritional differences and similarities among various types of plants and plant tissues. Plants for which detailed compositional data are available are largely among the economic plants. The limited number of plant materials considered in this chapter were chosen arbitrarily from among the edible seeds, roots, stems, petioles, leaves, flowers, fruits, and tubers in an attempt to obtain a broad, but concise appreciation of the

PROBABLE PATHWAYS OF INTERMEDIARY PLANT METABOLISM

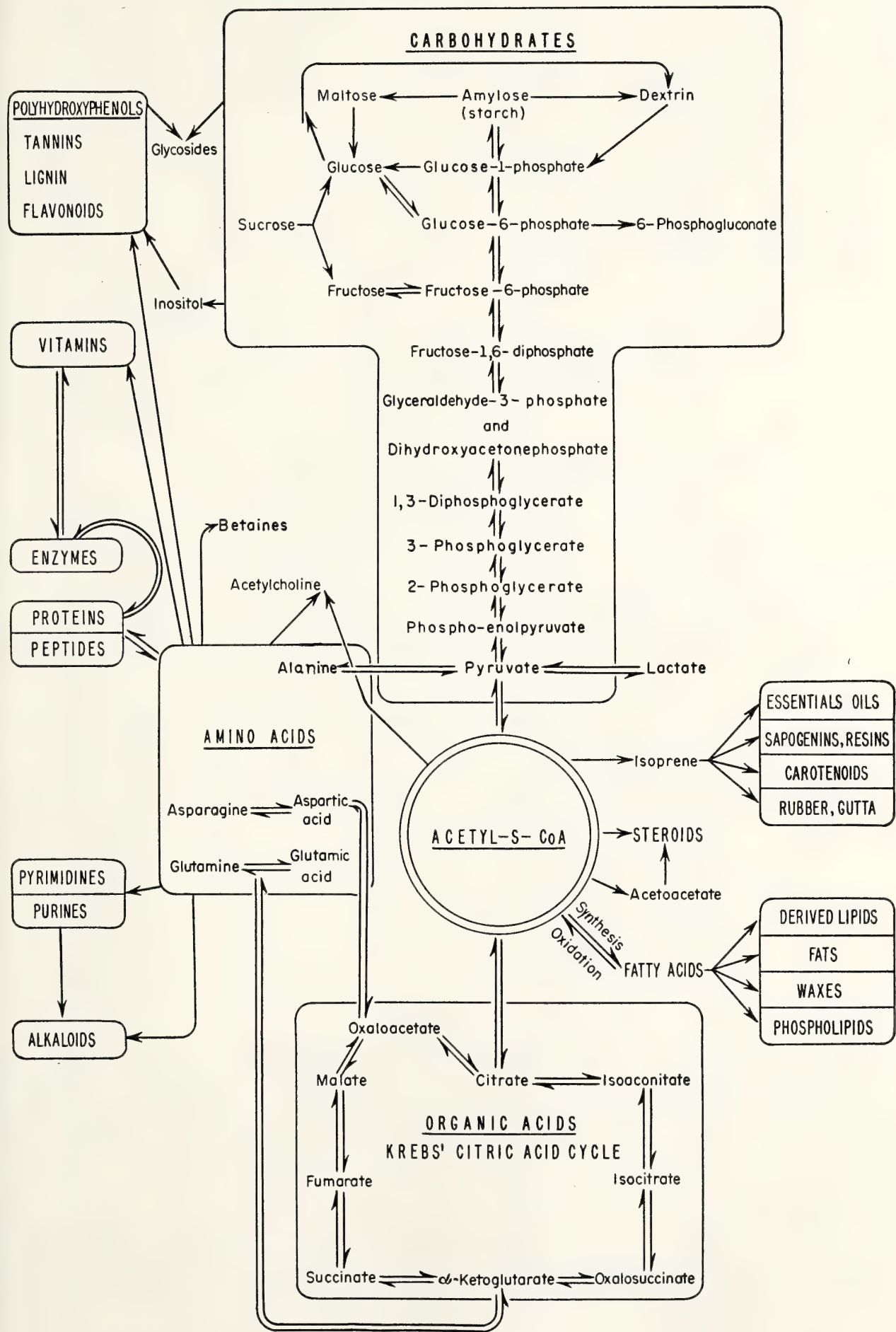


Figure 19-1.

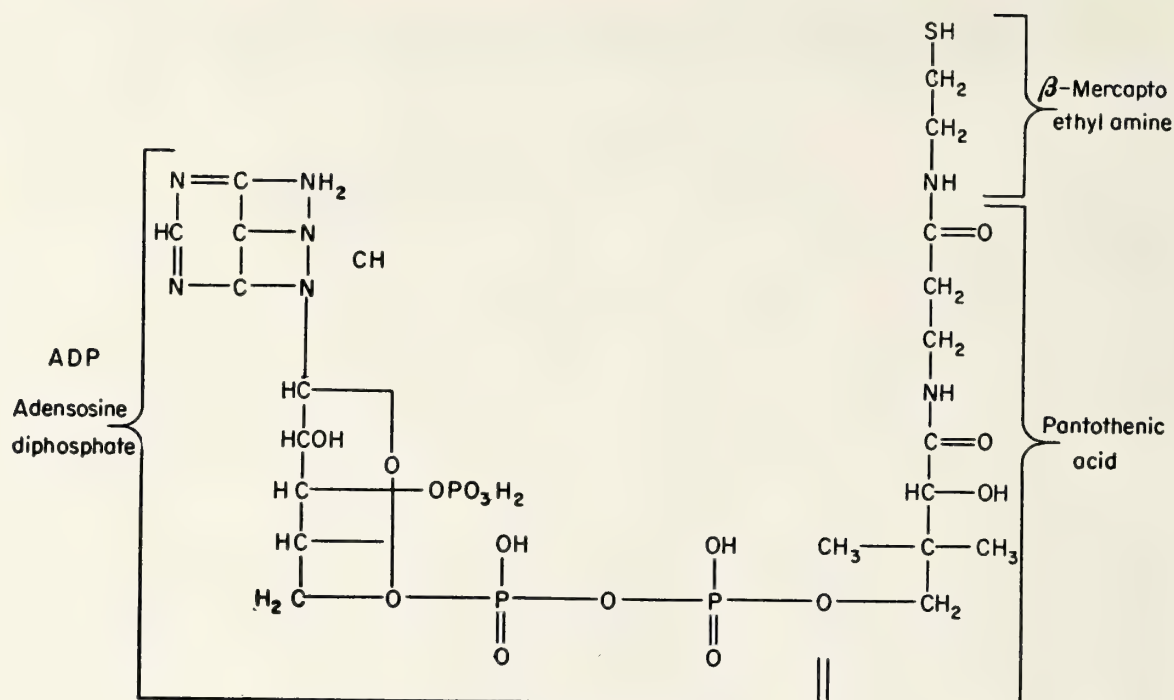


Figure 19-2. Coenzyme A (HS—CoA).
(Acetyl—S—CoA=CH₃—C—S—CoA)
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TABLE 19-2. SOME RADIOISOTOPES USEFUL IN BIOCHEMICAL INVESTIGATIONS

Element	Mass	Half life	Element	Mass	Half life
Hydrogen	3	30 years	Calcium	39	4.5 minutes
Carbon	11	21 minutes		41	8.5 days
	14	5000 years		45	180 days
Nitrogen	13	9.9 minutes		49	2.5 hours
Oxygen	15	2.1 minutes	Iron	53	8.9 minutes
Sodium	22	3 years		55	4 years
	24	14.8 hours		59	47 days
Magnesium	27	10.2 minutes	Iodine	124	4 days
Phosphorus	30	2.6 minutes		126	13 days
	32	14.3 days		128	25 minutes
Sulfur	35	88 days		130	12.6 hours
				131	8 days

chemical composition of higher plants. Variations in composition due to varietal differences, physical and chemical environment, maturity and other variables have not been considered and therefore only gross qualitative comparisons of plant materials are possible.

Proximate Analyses

Solids. The total solids contained in 29 plant products chosen arbitrarily from among the edible seeds, tubers, roots, sprouts, petioles, stems,

TABLE 19-3. APPROXIMATE SOLIDS IN VARIOUS EDIBLE PLANT PRODUCTS

Material	Tissue	Amount (%)	Material	Tissue	Amount (%)
Pecan	Seed, nut	97	Orange	Fruit juice	13
Peanut	Seed, legume	97	Beet, red	Root	12
Walnut	Seed, nut	97	Carrot	Root	12
Almond	Seed, nut	95	Strawberry	Fruit	10
Soybean	Seed, legume	93	Broccoli	Flower	10
Bean, common	Seed, legume	89	Cauliflower	Flower	8
Rice	Seed, cereal	88	Cabbage	Leaf	8
Corn	Seed, cereal	88	Spinach	Leaf	7
Wheat	Seed, cereal	87	Asparagus	Stem	7
Avocado	Fruit	35	Tomato	Fruit	6
Pea, fresh green	Seed, legume	26	Celery	Petiole	6
Potato, white	Tuber	22	Rhubarb	Petiole	5
Grape	Fruit	18	Squash, summer	Fruit	5
Apple	Fruit	16	Lettuce	Leaf	5
Soybean	Sprout	14			

leaves, fruits and flowers are shown in Table 19-3. It may be seen that the mature seeds all contain greater than 85 per cent solids, the high oil (nut) seeds containing less moisture than the cereal seeds. The roots and tuber contain from 10 to 25 per cent while the leaves, stems, petioles and flowers contain only from 5 to 10 per cent solids. The fruits are more variable, ranging from 6 per cent in summer squash to 35 per cent solids in avocado. Most fruits contain less than 20 per cent solids.

Crude Protein. The crude protein ($N \times 6.25$) content of the 29 plant products is presented in Table 19-4. It is of interest that on a moisture-free

TABLE 19-4. CRUDE PROTEIN IN VARIOUS EDIBLE PLANT PRODUCTS
(Calculated to a moisture-free basis)

Material	Tissue	Amount (%)	Material	Tissue	Amount (%)
Soybean	Sprout	45	Wheat	Seed, cereal	15
Soybean	Seed, legume	38	Corn	Seed, cereal	14
Broccoli	Flower	33	Beet, red	Root	13
Spinach	Leaf	32	Squash, summer	Fruit	12
Asparagus	Stem	31	Carrot	Root	10
Cauliflower	Flower	29	Rhubarb	Petiole	10
Peanut	Seed, legume	27	Pecan	Seed, nut	10
Pea, fresh green	Seed, legume	26	Potato, white	Tuber	9
Bean, common	Seed, legume	24	Rice	Seed, cereal	8
Lettuce	Leaf	23	Grape	Fruit	8
Celery	Petiole	21	Orange	Fruit juice	6
Almond	Seed, nut	20	Avocado	Fruit	5
Cabbage	Leaf	18	Strawberry	Fruit	5
Tomato	Fruit	17	Apple	Fruit	2
Walnut	Seed, nut	16			

basis soybean sprouts (45 per cent protein) contain only slightly less proteinaceous material than whole egg (50 per cent protein). Several other plant products, including soybean, broccoli, spinach, asparagus and cauliflower contain more protein than whole milk (27 per cent). On a moisture-free basis the crude protein content of the plant products listed in Table 19-4 follow the order: sprouts > leaves > flowers > stems > seeds > roots > fruits.

Carbohydrates. The crude carbohydrate, fiber and nutritionally available carbohydrate present in the 29 plant products are listed in Table 19-5. It is evident that the leaves, stems and flowers contain the highest and the seeds the lowest percentages of fiber. The fruits and cereal seeds have the highest proportions of available carbohydrate, 60 to 88 and 75 to 85 per cent, respectively, whereas the nut seeds contain the smallest amount, 10 to 18 per cent, of available carbohydrate.

TABLE 19-5. CRUDE CARBOHYDRATE CONTENT OF VARIOUS EDIBLE PLANT PRODUCTS

(Calculated to a moisture-free basis)

Material	Tissue	Carbohydrate, crude (%)	Fiber (%)	Carbohydrate, available (%)
Apple.....	Fruit	94	6	88
Rice.....	Seed, cereal	88	1	87
Potato, white.....	Tuber	86	2	84
Orange.....	Fruit, juice	88	5	83
Grape.....	Fruit	82	3	79
Wheat.....	Seed, cereal	82	3	79
Corn.....	Seed, cereal	79	3	76
Beet, red.....	Root	78	7	71
Squash, summer.....	Fruit	78	7	71
Carrot.....	Root	79	9	70
Strawberry.....	Fruit	82	14	68
Bean, common.....	Seed, legume	70	5	65
Rhubarb.....	Petiole	75	14	61
Pea, green.....	Seed, legume, immature	69	9	60
Tomato.....	Fruit	68	10	58
Cabbage.....	Leaf	70	13	57
Cauliflower.....	Flower	59	11	48
Celery.....	Petiole	59	11	48
Asparagus.....	Stem	56	10	46
Lettuce.....	Leaf	56	12	44
Broccoli.....	Flower	55	13	42
Spinach.....	Leaf	44	8	36
Soybean.....	Sprout	39	6	33
Almond.....	Seed, nut	21	3	18
Walnut.....	Seed, nut	16	4	12
Pecan.....	Seed, nut	13	2	11
Avocado.....	Fruit	15	5	10

TABLE 19-6. CRUDE LIPIDE CONTENT OF VARIOUS EDIBLE PLANT PRODUCTS
(Calculated to a moisture-free basis)

Material	Tissue	Amount (%)	Material	Tissue	Amount (%)
Avocado	Fruit	75	Cabbage	Leaf	2.5
Pecan	Seed, nut	75	Carrot	Root	2.5
Walnut	Seed, nut	67	Wheat	Seed, cereal	2.5
Almond	Seed, nut	57	Cauliflower	Flower	2.5
Peanut	Seed, legume	45	Apple	Fruit	2.5
Soybean	Seed, legume	20	Squash, summer	Fruit	2
Soybean	Sprout	10	Rice	Seed, cereal	2
Grape	Fruit	8	Rhubarb	Petiole	2
Tomato	Fruit	5	Broccoli	Flower	2
Strawberry	Fruit	5	Beans, common	Seed, legume	2
Corn	Seed, cereal	4	Orange	Fruit juice	1.5
Lettuce	Leaf	4	Pea, fresh green	Seed, legume	1.5
Spinach	Leaf	4	Beet, red	Root	1
Celery	Petiole	3	Potato, white	Root	0.5
Asparagus	Stem	3			

Lipides. The crude lipides in the 29 plant tissues, calculated as percentages of the total solids, are shown in Table 19-6. With the exception of avocado, the nut and the legume seeds, all of the products contain less than 10 per cent of solvent-extractable material. The tuber, roots, stems, petioles, leaves, fruits and cereal seeds contain less than 5 per cent of crude lipoidal material.

Ash. On a moisture-free basis, the green leaves, petioles, stems and flowers contain the largest amounts of inorganic solids as shown in Table 19-7. All the seeds yield less than 5 per cent ash, the nut and cereal seeds

TABLE 19-7. ASH IN VARIOUS EDIBLE PLANT PRODUCTS
(Calculated to a moisture-free basis)

Material	Tissue	Amount (%)	Material	Tissue	Amount (%)
Spinach	Leaf	20	Potato, white	Tuber	4.5
Lettuce	Leaf	17	Beans, common	Seed, legume	4.5
Celery	Petiole	17	Avocado	Fruit	4
Rhubarb	Petiole	14	Pea, fresh green	Seed, legume	3.5
Broccoli	Flower	11	Orange	Fruit, juice	3
Cabbage	Leaf	10	Corn	Seed, cereal	3
Cauliflower	Flower	10	Almond	Seed, nut	3
Asparagus	Stem	10	Peanut	Seed, legume	3
Tomato	Fruit	10	Walnut	Seed, nut	2
Beet, red	Root	9	Pecan	Seed, nut	2
Carrot	Root	9	Wheat	Seed, cereal	2
Squash, summer	Fruit	8	Grape	Fruit	2
Soybean	Sprout	6	Apple	Fruit	2
Soybean	Seed, legume	5	Rice	Seed, cereal	1
Strawberry	Fruit	5			

usually giving less than 3 per cent nonvolatile ash. The fruits contain variable amounts of inorganic solids, ranging from 2 per cent in apple to 10 per cent ash in tomato. With the exception of the seeds, the ash generally constitutes from 1 to 2 per cent of the wet weight of the plant material. The ash obtained from seeds is usually 1 to 5 per cent of the total solids.

Enzymes

The theory of "dynamic equilibrium" requires that mechanisms exist in living tissues through which exceedingly rapid chemical reactions may occur at essentially constant temperature. Not only must mechanisms exist for the transfer of energy but by comparison with *in vitro* reactions, the activation energy of these reactions must be of somewhat lower order. The relationship between reaction rate and activation energy is given by the familiar Arrhenius equation:

$$V = Ae^{-Ea/RT}$$

It may be calculated readily that a decrease in activation energy from 20,000 cal/mol to 10,000 cal/mol corresponds to an increase in reaction velocity of roughly 500,000 times at normal temperatures. Activation energies of uncatalyzed hydrolytic reactions are compared with the activation energies of corresponding enzymatically catalyzed reactions in Table 19-8. Other linked, enzymatically induced reactions assist in providing the energy required for the maintenance of the dynamic state. It is reasonable to believe that both plant and animal tissues contain several hundreds of enzyme systems, many of which may catalyze the same reactions independent of the biological origin of the enzymes. It is also highly probable that similarly functioning enzymes are not chemically identical. Although several apparently pure, crystalline enzymes have been prepared, knowledge of their composition, structure and mechanism of function is very incomplete. All known enzymes are proteins, ranging in molecular weights

TABLE 19-8. ACTIVATION ENERGIES OF VARIOUS UNCATALYZED AND ENZYMATICALLY CATALYZED REACTIONS

Reaction	Enzyme	Activation energy (<i>Ea</i>) (cal/mol)	
		No catalyst or H ions alone	Enzyme catalyst
Hydrogen peroxide decomposition	Catalase	18,000	5,000
Sucrose hydrolysis	β -Fructosidase	26,000	11,500
Casein hydrolysis	Trypsin	20,600	12,000
Ethyl butyrate hydrolysis	Lipase	13,200	4,200

from 13,000 for cytochrome c to 483,000 for urease. Many of the vitamins, especially members of the B-complex, function as prosthetic groups on the protein molecules. In general, enzymes contained in plant materials are present in very low concentrations and it is impractical to consider the enzyme content of particular plants in terms of percentage composition. However, in a few rare instances (e.g., about 0.1 per cent urease in jack bean meal) the enzyme content may approach a measurable proportion of the total solids. In Table 19-9 are shown some of the enzymes which have been characterized in various plant materials. The relative activities of peroxidase and glutamic acid oxidase in plant tissues shown in Table 19-10 indicate the gross differences that may exist in the enzyme activities of different types of plant materials. The enzyme activities of seeds are generally low compared to sprouts, fruit and other tissues exhibiting high respiratory rates. Although the respiration rate of dormant seeds may be very low, high velocity chemical reactions may occur in "dynamic equilibrium" with minimal energy loss to the environment.

Proteins

The major portion of the nitrogen in the tissues of higher plants is generally considered to be present in the form of protein. However, free amino acids, glutamine, asparagine, betaines, glutathione and other simple peptides may be present in appreciable amounts, especially in seedlings and sprouts. The classification of proteins is usually based upon their solubilities in various solvents and their heat coagulability. Plant proteins may be divided into six groups, as follows:

(1) **Albumins**—soluble in water and dilute salt solutions; heat coagulable; precipitated by saturated ammonium sulfate. The plant albumins are found among the reserve proteins of many seeds, e.g., leucosin from wheat.

(2) **Globulins**—insoluble in water; soluble in dilute solutions of neutral salt of strong acids and bases; heat coagulable; precipitated by half-saturated ammonium sulfate and other salts in moderate concentrations. The globulins are also found in the reserve proteins of many seeds, e.g., hemp (edestin), Brazil nut (excelsin) and almond (amandin).

(3) **Glutelins**—insoluble in all neutral solvents; soluble in dilute acid and alkali. Theutelins constitute an important fraction of the cereal seed proteins. Examples of theutelins include glutenin from wheat and oryzenin from corn.

(4) **Prolamines**—insoluble in water, neutral salt solutions, and absolute alcohol; soluble in 50 to 80 per cent ethyl alcohol, dilute acid and alkali. The prolamines compose the major portion of the proteins in many cereal seeds including corn (zein), wheat (gliadin) and barley (hordein).

TABLE 19-9. SOME ENZYMES CHARACTERIZED IN THE TISSUES OF HIGHER PLANTS

Tissue	Source	Enzyme
Seed	Barley	β -Amylase Glycolic acid oxidase
	Castor bean	Catalase α -Hydroxyacid oxidase Lipase Polyphenol oxidase
	Pea	Aldolase Phosphoglyceric acid kinase Phosphohexokinase
	Peanut Bitter almond Wheat Jack bean	Arachain Emulsin Lipase Urease
Sprout or seedling	Barley	Ascorbic acid oxidase Peroxidase
	Oat	Alcohol dehydrogenase Fumarase Glutamic acid dehydrogenase Isocitric acid dehydrogenase Malic dehydrogenase
Epicotyl	Pea	Indoleacetic acid oxidase
Root	Sweet potato Horseradish Sugar beet	α -Amylase Peroxidase Polyphenol oxidase
Tuber	Potato	Aldolase Amylase Alkaline phosphatase Glucose phosphate dehydrogenase Hexo(fructo)kinase Hexo(gluco)kinase Invertase Phosphofructokinase Phosphoglucomutase Phosphohexose isomerase Phosphorylase

TABLE 19-9.—*Continued*

Tissue	Source	Enzyme
Leaf	Bean	Ascorbic acid oxidase Glycolic acid oxidase
	Many green plants Tobacco, tea, apple Milkweed	Chlorophyllase Polyphenol oxidase Mexicanain
Latex	Milkweed (fruit) Papaya (fruit) Fig (fruit) Spurge Jabillo	Asclapain, Mexicanain Chymopapain, papain Ficin Euphorbain Hurain
	Squash Pineapple Maya Peach, apple, tomato Horsenettle	Ascorbic acid oxidase Bromelin Pinguinain Polyphenol oxidase Solanain

(5) **Albuminoids**—a diverse group of proteins insoluble in all neutral solvents.

(6) **Conjugated Proteins**—(a) Nucleoproteins; protein + nucleic acid, e.g., in spinach and tobacco leaves. (b) Chromoproteins; protein + chromophore, e.g., phycoerythrin and phycocyan in seaweed.

The distribution of various types of proteins in some whole cereal seeds is shown in Table 19-11. It may be seen that the prolamines and glutelins account for from 50 to 100 per cent of the total proteinaceous material. Other seeds, such as peanut and sunflower, contain a major proportion of globulins. The amino acid composition of several purified plant proteins is given in Table 19-12. The prolamines contain the highest proportions of glutamic acid and proline, no glycine and very small amounts of lysine and serine. The plant globulins, characterized by large amounts of arginine and fair proportions of glutamic acid and lysine, have a more uniform distribution of amino acids than the prolamines. Incomplete analyses of "crude" protein in various roots, seeds, sprouts, petioles, leaves, flowers, fruits and white potato tuber are shown in Table 19-13. The figures presented for many of the amino acids, especially cystine, methionine, serine, threonine, and tyrosine, may be considered as minimum values since many of the amino acids may be destroyed partially during acid hydrolysis of the protein in the presence of carbohydrates, lipides and other impurities. Insufficient data are available for satisfactory comparisons of the amino acid composition of the various plant tissues. However, the amino acid percent-

TABLE 19-10. PEROXIDASE AND GLUTAMIC ACID DECARBOXYLASE ACTIVITIES OF VARIOUS PLANT TISSUES

Source	Tissue	Peroxidase (units/kilo)	Glutamic acid decarboxylase ^a (CO ₂ /g, 30 min, mm ³)
Squash, yellow.....	Fruit	—	600
Avocado.....	Fruit	—	490
Parsley.....	Leaf	—	274
Cucumber.....	Fruit	—	260
Asparagus tip.....	Stem	—	223
Carrot.....	Root	—	222
Celery.....	Leaf	—	189
Peas, green.....	Seed	—	149
Lettuce.....	Leaf	—	64
Cabbage, green.....	Leaf	—	62
Spinach.....	Leaf	—	58
Barley.....	Sprout	550	—
Potato, white.....	Tuber	36	—
Beet.....	Root	11	48
Corn.....	Seed	—	25
Tomato.....	Fruit	—	21
Sunflower.....	Seed	—	8
Broccoli.....	Flower	—	8
Cauliflower.....	Flower	—	4
Wheat.....	Seed	10	—
Barley.....	Seed	9	—
Oat.....	Seed	3	—
Soybean.....	Seed	2	—

^a per gram fresh weight.

TABLE 19-11. AMOUNTS OF VARIOUS PROTEINS IN WHOLE DRY SEEDS

Plant	Prolamine (%)	Glutelin (%)	Globulin (%)	Albumin (%)	Total (%)
Sorghum.....	7.9	—	—	—	7.9
Corn.....	5.0	0.7	—	—	5.7
Wheat.....	4.2	1.0	0.6	0.3	6.1
Rye.....	4.0	—	—	0.4	4.4
Barley.....	4.0	—	—	0.3	4.3
Rice.....	0.1	1.5	0.2	—	1.8

ages in some of the individual plant proteins are quite distinctive. The lysine content of celery, soybean sprouts and the cereal seed proteins are low in comparison with other plant proteins and most animal proteins. Most of the plant proteins and especially the legume seeds, soybean sprouts, carrot, beet and rhubarb are low in methionine. The root, petiole, spinach, broccoli and apple proteins appear to be deficient in histidine. The arginine and valine content of peanut and the arginine and lysine content of soybean proteins are high even in comparison with many animal proteins. Soybean

TABLE 19-12. APPROXIMATE AMINO ACID COMPOSITION OF SOME PARTIALLY PURIFIED PLANT PROTEINS

Source	Wheat				Corn	Hemp-seed	Cotton-seed	Coco-nut	Soy-bean	Peanut
Common name	Gluten	Leu-cosin	Glute-nin	Gliadin	Zein	Edestin			Gly-cinin	Arachin
Class	Glute-lin, prola-mine	Albu-min	Glutelin	Prola-mine	Prola-mine	Glo-bulin	Glo-bulin	Glo-bulin	Glo-bulin	Glo-bulin
Animo acid	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Alanine	2.2	4.5	4.7	2.0	9.8	3.6	4.5	4.1	1.7	4.1
Arginine	4.5	5.9	4.7	2.6	1.7	16.3	12.2	15.9	8.3	13.5
Aspartic acid . . .	3.7	3.4	2.0	0.8	2.6	11.1	—	5.1	5.7	5.3
Cystine	1.9	—	1.8	2.4	0.9	1.2	1.1	1.5	1.1	1.5
Glutamic acid . .	35.5	6.7	25.7	43.7	31.3	20.0	—	19.1	21.9	16.7
Glycine	3.5	0.9	0.9	0.0	0.0	3.8	1.2	—	3.8	1.8
Histidine	2.3	2.8	1.8	2.4	0.9	2.3	3.0	2.4	2.2	1.9
Hydroxyproline .	—	—	—	—	0.8	2.0	—	2.0	—	0
Isoleucine	4.6	11.3	6.0	6.6	23.7	20.9	2.4	6.0	6.6	—
Leucine	7.6				4.3		8.7		8.0	3.9
Lysine	1.8	2.8	1.9	0.7	0.0	2.3	5.2	5.8	6.1	5.0
Methionine	1.9	—	—	2.1	2.4	2.3	2.5	—	1.1	0.7
Phenylalanine . .	5.4	3.8	2.0	2.4	7.0	3.1	8.4	—	5.6	2.6
Proline	12.7	3.2	4.2	13.2	9.0	4.1	2.3	5.5	4.3	1.4
Serine	4.7	—	0.7	0.1	1.0	0.3	2.9	1.8	—	5.2
Threonine	2.6	—	—	—	2.2	—	2.9	—	2.1	2.6
Tryptophan	1.1	—	1.7	1.1	0.2	1.5	1.4	1.3	1.7	0.9
Tyrosine	3.1	3.3	4.5	3.0	5.4	4.6	3.4	3.2	3.9	5.5
Valine	4.7	0.2	0.2	3.4	2.2	3.4	6.6	3.6	5.0	1.1
Ammonia	4.5	1.4	4.0	5.2	3.6	2.3	—	1.6	—	2.0
Total	108.3	50.2	66.8	91.7	109.1	105.1	68.7	78.9	89.1	75.7

sprouts appear to be one of the richest sources of aspartic acid. However, it is probable that most of the aspartic acid represents asparagine converted to aspartic acid during acid hydrolysis of the plant material. Serine appears to be deficient in carrot and unusually high in corn proteins. Low values for methionine are found in soybean and apple proteins. The glutamic acid content of plant proteins is quite variable, ranging from 4.5 per cent in soybean to 29 per cent in wheat proteins.

Free Amino Acids

The occurrence of unusually large amounts of asparagine and glutamine in plant seedlings and sprouts is well known. However, the presence in

TABLE 19-13. APPROXIMATE AMINO ACID COMPOSITION OF "CRUDE" PROTEIN IN SOME COMMON PLANTS

Amino acid	Seeds				Sprouts		Roots		Petioles		Leaf			Flower	Fruit	Tuber		
	Cereal				Legume		Soybean (%)	Carrot (%)	Beet (%)	Celery (%)	Rhub- arb (%)	Spinach (%)	Grass (%)	Alfalfa (%)	Broccoli (%)	Apple (%)	White Potato (%)	
	Wheat (%)	Corn (%)	Rice (%)	Oats (%)	Peanut (%)	Pea (%)												Soybean (%)
Alanine.....	—	—	—	—	4.3	—	—	—	—	—	—	—	—	—	—	—	—	
Arginine	4.3	4.8	4.2	6.8	11.3	4.6	3.6	4.3	4.1	4.0	4.7	4.4	7.0	4.3	4.8	3.5	5.0	
Aspartic acid..	—	—	—	—	5.8	—	30.4	—	—	—	—	7.7	5.3	—	—	4.3	—	
Cystine.....	1.8	1.5	1.3	1.8	1.9	1.2	—	—	—	—	—	2.1	2.0	1.6	—	1.1	—	
Glutamic acid.	29.0	—	—	—	19.2	—	4.5	—	—	—	—	9.7	11.5	—	—	6.1	—	
Glycine.....	—	—	—	—	5.6	—	2.1	—	—	—	—	—	—	—	—	2.9	—	
Histidine.....	2.1	2.5	1.7	2.3	2.1	1.6	2.1	1.9	1.3	1.5	1.9	1.3	2.0	2.1	1.5	1.4	2.2	
Isoleucine.....	4.0	3.6	6.3	4.9	4.6	4.4	3.6	4.5	4.2	3.9	4.0	3.6	5	3.6	3.2	5.3	3.7	
Leucine	6.7	6.9	8.2	8.0	7.0	7.8	4.3	7.1	6.4	6.8	8.4	6.8	10	6.6	6.4	5.2	4.6	
Lysine	2.7	3.2	3.2	3.6	3.4	4.9	3.4	4.5	5.4	2.4	5.4	4.7	5.5	4.9	4.5	4.0	5.2	
Methionine.....	2.5	3.1	2.3	2.0	1.2	1.0	0.7	1.7	1.7	2.2	1.0	2.3	2.5	2.3	1.8	1.7	2.5	
Phenylalanine.	5.3	5.4	4.7	5.5	5.4	6.0	3.0	6.5	5.8	4.5	6.1	4.7	5.5	4.5	6.0	3.3	5.9	
Proline.....	—	—	—	—	—	5.8	—	—	—	—	—	—	3	—	—	4.2	—	
Serine.....	4.3	8.5	—	—	—	4.2	—	1.5	—	—	—	—	6.2	—	—	3.6	—	
Threonine.....	3.3	3.7	3.8	3.6	2.9	4.4	2.6	4.4	3.8	3.4	4.0	3.9	5.4	3.3	3.3	3.1	2.5	
Tryptophan...	1.2	1.3	1.3	1.3	1.0	1.5	—	1.4	1.2	1.3	1.6	1.9	2.2	1.6	1.4	0.0	2.2	
Tyrosine.....	4.0	6.0	5.7	4.5	4.4	—	—	—	—	—	—	5.4	5.0	5.7	—	—	—	
Valine.....	4.3	5.3	6.3	5.4	8.0	5.7	3.6	5.5	5.1	5.5	5.3	5.0	5	4.4	4.5	3.7	5.3	
Total	75.5	55.8	49.0	49.7	88.1	53.1	63.9	43.3	39.0	35.5	42.4	63.5	83.1	44.9	37.4	53.4	39.1	

many well-developed higher plant tissues of relatively large quantities of free amino acids has been recognized only recently through the medium of newly elaborated analytical techniques. These new procedures, including microbiological analysis, filter paper electrophoresis, filter paper and ion-exchange chromatography, have also aided in the identification of several new amino acids and related compounds in various biological materials.

Most of the analyses performed thus far have been of a qualitative character, although a few quantitative studies have been reported. The results of some qualitative and semiquantitative estimations of free amino acids in the tissues of several plants are shown in Table 19-14. It may be seen that free aspartic and glutamic acids have been detected in all of the plant products investigated. Alanine, γ -aminobutyric acid, asparagine, glutamine, leucine, isoleucine, serine, threonine and valine have been found in one or more of the seeds, sprouts, roots, stems, leaves, fruits and tubers. Arginine, lysine methionine and phenylalanine appear to be present in most seeds and variable, absent or undetected in most other tissues. Proline was found in most seeds, leaves and all fruits except avocado. Traces of hydroxyproline have been observed only in apple fruit and prune extracts. Free tryptophan has been detected only in the legume seeds, soybean sprouts and apple fruit.

A number of new amino acids and related compounds have been discovered in a wide variety of plant juices and extracts. Gamma-methylene glutamine and gamma-methylene glutamic acid have been reported in peanut seedlings but not in the dormant seeds. Putrescine has been detected in barley leaves and orange juice. Pipicolinic acid occurs widely, having been found in mushrooms, broad bean, Rhodesian teak, white clover, peas, carrot, cabbage and leek. Bean seedlings contain the tripeptide, glutathione, while the citrus juices contain both glutathione and cysteine. It is of interest that over 90 per cent of the total nitrogen in citrus juices is present in the form of free amino acids and related compounds. On a moisture-free basis these compounds constitute from 5 to 10 per cent of the total solids. It might be expected that a significant proportion of the so-called crude protein ($N \times 6.25$) in other plant juices and tissues may be similarly composed largely of free amino acids, simple peptides and related substances.

Carbohydrates

Carbohydrate, formed by plants from carbon dioxide and water during photosynthesis, is the basic fuel providing the energy required for other metabolic processes. The plant carbohydrates may be classified according to both functional and chemical characteristics. On a purely chemical basis, the aliphatic polyhydroxy compounds containing carbon, hydrogen and oxygen may be classified as shown in Table 19-15. Functionally, the carbohydrates may be categorized according to whether they are constituents of

TABLE 19-14. SOME FREE AMINO ACIDS AND RELATED COMPOUNDS IN PLANT TISSUES

Compound	Seed				Sprout		Root							Stem				Peti- ole	Leaf						Blos- som	Fruit							Tuber	
	Peanut	Soybean	Wheat (flour)	Barley	Barley	Soybean cotyledon	Soybean	Garden bean	Pea	Alfalfa	Alder ^a	Beet, red ^b	Carrot	Alder ^a	Cane (juice) ^b	Apple (tracheal sap)	Apple (branches)	Celery	Alder ^a	White clover	Rye grass ^b	Apple	Parsley	Cabbage	Apple	Apple	Prune	Apricot	Avocado	Orange juice ^b	Grapefruit juice	Lemon juice ^b	Potato ^b	
Alanine.....	+			+		+	+	+	+	+	+	+	+	2	15		+	+	+	8	+	+	+	+	+	+	+	+	+	+	+	+	+	19
β-Alanine.....																																		54
α-Aminobutyric	+					+	+	+	+	+	+	+	+	3	18		+	+	+	9	+	+	+	+	+	+	+	+	+	+	+	+	+	16
γ-Aminobutyric						+	+	+	+	+	+	+	+	10						46	+	+	+	+	+	+	+	+	+	+	+	+	+	230
Arginine.....	+			+		+	+	+	+	+	35	+	+							26	+	+	+	+	+	+	+	+	+	+	+	+	+	
Aspartic acid...						+	+	+	+	+		+	+								+	+	+	+	+	+	+	+	+	+	+	+	+	
Asparagine.....	+			+		+	+	+	+	+		+	+								+	+	+	+	+	+	+	+	+	+	+	+	+	
Citrulline.....						+	+	+	+	+		+	+								+	+	+	+	+	+	+	+	+	+	+	+	+	
Cysteine.....						+	+	+	+	+		+	+								+	+	+	+	+	+	+	+	+	+	+	+	+	
Cystine.....						+	+	+	+	+		+	+								+	+	+	+	+	+	+	+	+	+	+	+	+	
Glutamic acid.						+	+	+	+	+		+	+								+	+	+	+	+	+	+	+	+	+	+	+	+	
Glutamine.....						+	+	+	+	+		+	+								+	+	+	+	+	+	+	+	+	+	+	+	+	
Glutathione.....						+	+	+	+	+		+	+								+	+	+	+	+	+	+	+	+	+	+	+	+	
Glycine.....	+			+		+	+	+	+	+		+	+								+	+	+	+	+	+	+	+	+	+	+	+	+	
Histidine.....	+			+		+	+	+	+	+		+	+								+	+	+	+	+	+	+	+	+	+	+	+	+	
Hydroxyproline.....						+	+	+	+	+		+	+								+	+	+	+	+	+	+	+	+	+	+	+	+	
Isoleucine.....						+	+	+	+	+		+	+								+	+	+	+	+	+	+	+	+	+	+	+	+	
Leucine.....						+	+	+	+	+		+	+								+	+	+	+	+	+	+	+	+	+	+	+	+	
Lysine.....						+	+	+	+	+		+	+								+	+	+	+	+	+	+	+	+	+	+	+	+	
Methionine.....						+	+	+	+	+		+	+								+	+	+	+	+	+	+	+	+	+	+	+	+	
Phenylalanine.						+	+	+	+	+		+	+								+	+	+	+	+	+	+	+	+	+	+	+	+	
Pipicolinic acid						+	+	+	+	+		+	+								+	+	+	+	+	+	+	+	+	+	+	+	+	
Proline.....						+	+	+	+	+		+	+								+	+	+	+	+	+	+	+	+	+	+	+	+	
Serine.....						+	+	+	+	+		+	+								+	+	+	+	+	+	+	+	+	+	+	+	+	
Threonine.....						+	+	+	+	+		+	+								+	+	+	+	+	+	+	+	+	+	+	+	+	
Tryptophan....						+	+	+	+	+		+	+								+	+	+	+	+	+	+	+	+	+	+	+	+	
Tyrosine.....						+	+	+	+	+		+	+								+	+	+	+	+	+	+	+	+	+	+	+	+	
Valine.....						+	+	+	+	+		+	+								+	+	+	+	+	+	+	+	+	+	+	+	+	

^a Based on dry weight, mg/100 g. ^b Based on wet weight, mg/100 g.
+ = Present; ± = found occasionally; - = Absent.

TABLE 19-15. CLASSIFICATION OF COMMON PLANT CARBOHYDRATES
ACCORDING TO CHEMICAL STRUCTURE

1. SUGARS
 - 1.1. Monosaccharides
 - 1.1.1. Pentoses ($C_5H_{10}O_5$)
 - 1.1.1.1. Arabinose
 - 1.1.1.2. Xylose
 - 1.1.1.3. Ribose
 - 1.1.1.4. Rhamnose (methyl pentose, $C_6H_{12}O_5$)
 - 1.1.2. Hexoses ($C_6H_{12}O_6$)
 - 1.1.2.1. Glucose
 - 1.1.2.2. Fructose
 - 1.1.2.3. Galactose
 - 1.1.2.4. Mannose
 - 1.1.2.5. Sorbose
 - 1.2. Disaccharides ($C_{12}H_{22}O_{11}$)
 - 1.2.1. Sucrose
 - 1.2.2. Maltose
 - 1.2.3. Cellobiose
 - 1.2.4. Melibiose
 - 1.2.5. Trehalose
 - 1.3. Trisaccharides ($C_{18}H_{32}O_{16}$)
 - 1.3.1. Raffinose
 - 1.3.2. Gentianose
 - 1.3.3. Melezitose
 - 1.4. Tetrasaccharides ($C_{24}H_{42}O_{21}$)
 - 1.4.1. Stachyose
2. POLYSACCHARIDES
 - 2.1. Pentosans
 - 2.1.1. Arabans
 - 2.1.2. Xylans
 - 2.2. Hexosans
 - 2.2.1. Cellulose
 - 2.2.2. Dextrins
 - 2.2.3. Fructosans
 - 2.2.4. Galactans
 - 2.2.5. Inulin
 - 2.2.6. Lichenins
 - 2.2.7. Mannans
 - 2.2.8. Starches
3. COMPOUND CARBOHYDRATES
 - 3.1. Uronides
 - 3.1.1. Gums
 - 3.1.2. Hemicelluloses
 - 3.1.3. Mucilages
 - 3.1.4. Pectins
 - 3.2. Glycosides
 - 3.2.1. Alkaloid
 - 3.2.2. Anthracene
 - 3.2.3. Phenol
 - 3.2.3.1. Anthocyanidin
 - 3.2.3.2. Anthoxanthin
 - 3.2.3.3. Tannin
 - 3.2.4. Sapogenin
 - 3.2.5. Sterol

TABLE 19-16. PLANT CELL WALL CONSTITUENTS

Constituent	Oat straw (%)	Corn cob (%)	Hop flower (%)
Carbohydrates			
Cellulose.....	44	38	31
Polyuronide hemicelluloses.....	23	42	10
Lignin.....	19	17	54
Noncellulosic polysaccharides (i.e., xylan).....	9	0.5	5
Pectic substances.....	1	0.5	—
	—	—	—
Total.....	96.0	98.0	100
Protein, crude.....	2	3.2	—
Ash.....	7	1.4	—
	—	—	—
Total.....	105.0	103.6	100

the skeletal framework of plant cells, as classified in Table 19-16, or whether they serve as a source of reserve energy, taking an active part in the oxidative, hydrolytic and synthetic mechanisms of intermediary metabolism, as illustrated in Figure19-1.

Only a relatively few carbohydrates, including some monosaccharides, disaccharides and polysaccharides, are of nutritional significance to humans. Nevertheless, the organoleptic and economic values of commercially produced plant products are dependent to a large extent upon the relative types and proportions of the carbohydrates present in the nonskeletal tissues. For example, pectic substances and gums, being intimately involved in texture and consistency characteristics of fruit, may be of major importance in determining the economic and organoleptic value of market fruits.

Sugars. Sweetness is one of the prime factors governing the organoleptic quality of edible plant products. Although many other plant constituents, such as the amino acids glycine, alanine, serine and others, contribute to sweetness, the disaccharide, sucrose, and the monosaccharides, glucose and fructose, are the principal constituents responsible for the sweet taste of fruit and other plant products. The approximate sweetness of various natural and derived plant sugars, as well as several synthetic sweetening agents, are shown in Table 19-17. Although the chemical basis for sweetness is still obscure, several very powerful sweetening agents have been prepared synthetically.

The approximate sugar content of various edible plant products is presented in Table 19-18. It may be seen that fruits contain by far the greatest proportion of sugars. On the other hand, seeds contain almost insignificant quantities of sugar.

The identities of the sugars in most plant products have not been established, although it is assumed that sucrose, glucose and fructose are the

TABLE 19-17. APPROXIMATE RELATIVE SWEETNESS SCALE

Material	Relative sweetness*
Perillaldehyde- α -anti-aldoxime.....	200,000
Saccharin.....	50,000
Cyclamate (cyclohexylsulfamates)....	3,000
D-Fructose.....	150
Invert sugar.....	125
Sucrose.....	100
D-Glucose.....	70
Corn syrup (enzyme).....	60
Maltose.....	50
Sorbitol.....	40
Glycerine.....	40
Corn syrup (acid).....	30
Lactose.....	20

* Sucrose taken as 100.

TABLE 19-18. APPROXIMATE SUGAR CONTENT OF VARIOUS EDIBLE PLANT PRODUCTS

(Calculated to a moisture-free basis)

Plant	Tissue	Sugar content (%)	Plant	Tissue	Sugar content (%)
Orange	Fruit juice	72	Celery	Petiole	19
Apple	Fruit	70	Corn	Seed	16
Carrot	Root	64	Pea	Seed	12
Grape	Fruit	63	Soybean	Seed	9
Tomato	Fruit	58	Rhubarb	Petiole	8
Strawberry	Fruit	52	Spinach	Leaf	4
Cabbage	Leaf	46	Potato	Tuber	4
Lettuce	Leaf	31	Pecan	Seed	4
Cauliflower	Flower	31	Almond	Seed	3
Broccoli	Flower	20	Avocado	Fruit	2
Squash, summer	Fruit	20	Walnut	Seed	2
Asparagus	Stem	19			

principal sugars in plant products. The nature of the individual sugars in several fruit juices, established largely through investigations employing filter paper chromatography techniques, is shown in Table 19-19.

Starch. Starch is the most abundant reserve carbohydrate of the plant kingdom. The approximate starch content of various plant products is given in Table 19-20.

Composed of water-soluble amylose and the less soluble amylopectin, starch may be hydrolyzed with dilute mineral acids to give quantitative yields of D-glucose. Amylose is primarily responsible for the blue color obtained by the addition of iodine to starch, yielding about six times the color (blue) produced by an equal weight of amylopectin (violet color with iodine). The ratio of amylose to amylopectin in the starches of various

TABLE 19-19. FREE SUGARS IN VARIOUS FRUIT JUICES

Generic name	Fruit	Glucose	Fructose	Sucrose	Maltose
<i>Citrus nobilis</i> , <i>C. sinensis</i>	Orange	+	+	+	+
<i>Punica granatum</i>	Pomegranate	+	+		+
<i>Syzygium cumini</i>	Black plum	+	+		+
<i>Mangifera indica</i>	Mango	+	+	+	+
<i>Cucumis melo</i>	Melon	+	+	+	+
<i>Litchi chinensis</i>	Lichi	+	+	+	+
<i>Artocarpus intergrifolia</i>	Jack-fruit	+	+	+	
<i>Grewia asiatica</i>	Falsa	+	+		+

plants appears to be inherited and is essentially the same, independent of growing conditions and stage of maturity. In a large number of plants the ratio of amylose to amylopectin is about 1:4. Among the plant seed starches the ratio may vary considerably. Waxy corn starch contains practically no amylose while wrinkled pea starch contains 70 per cent and smooth pea starch contains 36 per cent amylose, as indicated in Table 19-21.

Polyuronides. The pectic substances, polyuronide hemicelluloses, gums and mucilages, are the principal polyuronides present in higher plants. These polymeric uronic acid derivatives appear to function as intercellular cement and are responsible to a large measure for the consistency and texture of plant tissues. They are characterized by their ability to imbibe large quantities of water, forming viscous pastes or gels.

Mucilages are mixtures of protein and polyuronides, the latter usually containing galacturonic acid and simple sugars, such as galactose, rhamnose, arabinose, or xylose. The mucilages may also contain microscopically dispersed cellulose particles. Mucilages may be prepared by aqueous extraction of mustard seed, flax seed, slippery elm (*Ulmus fulva*) bark, and the seeds of *Brassica alba*, *Lepidium sativum* and *Plantago psyllium*.

Vegetable gums are found as exudates on plant roots, leaves and bark. Among the well known gums of commerce are gum arabic, gum guaiac, gum tragacanth, Damson gum, Mesquite gum, Karaya gum, Carob seed gum (Locust gum) and Ghati gum. The physical and chemical properties of the gums are similar to those of the mucilages. Some gums contain glucuronic acid while others contain galacturonic acid, together with simple sugars such as arabinose, rhamnose, mannose and galactose.

Polyuronide hemicelluloses are generally differentiated from the pectic substances, which they resemble chemically, on the basis of their solubility in alkali and their insolubility in water. However, it has been shown recently that chlorite-treated holocellulose (lignin-free mixture of cellulose and polyuronide hemicelluloses) may contain as much as 70 per cent of water-extractable hemicellulose. Therefore, the hemicelluloses have been redefined as those substances which may be extracted with water from pectin-free, chlorite-treated holocellulose.

TABLE 19-20. APPROXIMATE STARCH CONTENT OF VARIOUS PLANT PRODUCTS
(Calculated to a moisture-free basis)

Plant		Total starch (%)
Part	Name	
Seed	Rice, white (endosperm)	90
	Wheat (flour)	85
	Barley	81
	Rye	80
	Rice, whole	70
	Corn	70
	Sorghum	70
	Snap beans, whole	70
	Lima beans	47
	Peas, smooth	44
	Peas, wrinkled	34
	Cotton	10
	Almond	5
	Peanut	4
	Walnut	3
	Soybean	2
Root	Potato, sweet	60
	Parsnip	11
Stem	Asparagus	6
Petiole	Rhubarb	38
Leaf	Spinach	6
	Gladiolus	1
Flower	Jerusalem artichoke	27 (inulin)
Fruit	Pumpkin	26
	Orange, rind	13 (pectin)
	Squash, summer	10
Tuber	Potato, white	66

The holocelluloses compose the bulk of the plant cell wall constituents as indicated in Table 19-16. Although the hemicellulose polyuronides may amount to as much as 30 per cent of the dry weight of forage plants, this class of carbohydrates has received very little attention. The chemistry of the wood, seed and leaf hemicelluloses has been studied more extensively. In general, hemicelluloses appear to occur as mixtures of closely related compounds. Typical hemicelluloses contain either glucuronic or galacturonic acids com-

TABLE 19-21. APPROXIMATE AMYLOSE CONTENT OF STARCH IN VARIOUS PLANT PRODUCTS

Tissue	Plant	Amylose (%)
Seed	Corn, waxy	0
	Rice	17
	Wheat	27
	Pea (smooth)	36
	Pea (wrinkled)	70
Sprout	Potato	46
Leaf	Potato	18
Fruit	Banana	20
Tuber	Potato	22

TABLE 19-22. CHEMICAL COMPOSITION OF SOME PECTIN PREPARATIONS

Tissue	Plant	Galacturonic acid (%)	CHO ₃ - (%)	CH ₃ COO- (%)	L-Arabinose (%)	D-Galactose (%)	L-Xylose (%)
Root	Sugar beet	67.5	5.5	10.4	13.1	14.8	—
Stem	Flax stalk	61.2	4.1	8.6	10.9	13.9	10.9
Fruit	Orange, albedo	67.3	6.0	10.9	14.2	15.6	—
	Raspberry	75.7	11.2	10.7	14.9	—	—
	Strawberry	79.7	9.7	10.5	6.6	—	—
	Lemon, albedo	89.4	11.6	2.3	6.1	3.1	—

bined with polysaccharides containing a pentose, such as xylose or arabinose, and a hexose, such as glucose or galactose. Some hemicelluloses do not appear to contain a hexose moiety. Although the hemicelluloses appear to be utilized as reserve carbohydrates in several plant species, little is known concerning the intermediary metabolism of this class of compounds.

Pectic polyuronides contain a high proportion of glucuronic acid residues coupled with simple sugars such as arabinose and galactose. The chemical composition of several pectin preparations is presented in Table 19-22.

The pectic substances occur mainly in the primary cell wall although they are often found in plant juices and extracts. They differ from other components of the skeletal network, such as cellulose and lignin, in that they appear to be more intimately related to processes of intermediate carbohydrate metabolism. Pectic changes, brought about by release of pectic enzymes within the tissues affect the texture and appearance of many plant products and especially the fruits. Three distinct types of pectic enzymes are recognized:

(1) Protopectinase—attacks protopectin yielding soluble pectin. It may be found in ripening apples, rutabaga and other fruits and leaves.

(2) Pectinase—or polygalacturonase attacks pectic acid or pectin yielding galacturonic acid, xylose, arabinose and galactose. It is present in germinating barley, ripe or overripe fruits and has a pH optimum of 3.0–3.5.

TABLE 19-23. PECTIN CONTENT OF VARIOUS PLANTS
(Calculated to a moisture-free basis)

Tissue	Plant	Pectin (%)
Root	Carrot	7
	Beet pulp	25-30
Fruit	Apple pomace	15-18
	Lemon pulp	30-35
	Orange pulp	30-40

(3) Pectase—attacks pectin yielding pectinic or pectic acids. It is found universally in seeds, seedlings, tubers, roots and leaves.

The pectin content of several plant products is shown in Table 19-23. The very high proportion of pectin (30 to 40 per cent) in citrus peel and pulp favors the production of pectin from the abundant supply of citrus wastes produced by the citrus processing industry. Apple pomace, containing a smaller percentage of pectin but having somewhat different gelling properties, is also produced commercially.

Organic Acids

Aliphatic Acids. The aliphatic, non-nitrogenous organic acids are found ubiquitously among plant products as free acids, salts and phosphate esters. They are intimately involved in intermediary metabolism, many of them being end products and/or substrates in the Krebs' citric acid cycle as indicated in Figure 19-1. The organic acids are largely responsible for the tartness of many fruits such as apples, tomatoes, lemons, oranges and other citrus varieties. Mixtures of organic acids and their salts act as buffers stabilizing the pH of plant products. In citrus fruits the organic acids, mainly citric and malic acids, appear to be directly related to maturity. Very little reliable data is available on the organic acid content of plant products. However, some data that have been reported on the organic acids in various roots, stems and leaves are presented in Table 19-24.

Aromatic Acids. Aromatic organic acids occur universally in plant tissues as free acids, esters and glycosides. Many of the naturally occurring aromatic acids, such as *p*-coumaric, meliolic, gallic, caffeic, protocatechuic and salicylic acids, have phenolic character and may be readily converted into darkened, oxidation products by enzymatic reactions. The functions and metabolism of the aromatic organic acids in plants have not been elucidated. However, it has been suggested that they may function as prosthetic groups of enzymes, reversible oxidation-reduction systems, natural antibiotics, intermediary metabolites or simply end products of plant metabolism.

TABLE 19-24. APPROXIMATE ORGANIC ACID CONTENT OF VARIOUS ROOTS, STEMS, LEAVES AND FRUITS
(Calculated to a moisture-free basis)

Acid	Root		Stem			Leaf					Fruit						
	Carrot	Tobacco	Tobacco	Buckwheat	Tomato	Tomato	Buckwheat	Spinach	Rhubarb	Orange	Orange	Grapefruit	Lemon	Pineapple	Apple	Grape	Tomato
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Acetic ...																	0.22 ^a
Aconitic .																	0.39
Citric....	Trace	0.3	0.3	0.4	0.8	4.7	0.8	0.7	14.8	1.7	8.0	23	64	8.0		0.1	7.2
Formic . .																	0.07 ^a
Fumaric .	0.06																
Isocitric .	0.39														Trace		
Lactic ...																	0.16
Malic....	3.2	0.5	1.8	1.9	6.0	4.1	1.5	0.6	1.5	4.6	1.3	2.2	2.2	4.9	2.2	1.2	0.5
Oxalic ...		1.8	0.9	2.5	5.1	2.8	15.5	19.5	9.0	5.5							
Succinic .	0.65			0.2			0.2		0.03						Trace		
Tartaric .														2.6		2.2	

^a Mg per cent.

Lipides

The plant lipides (lipoids or lipins) are generally considered to include all the water-insoluble, organic solvent (chloroform, diethyl ether, benzene, etc.,)-soluble substances derived from all portions of plants including seeds, roots, stems, leaves, flowers and fruits. However, organic solvent extracts of plant tissues may also include essential oils, resins, resin acids, triterpenes, carotenoids and other terpenes which are discussed in later paragraphs.

The crude lipid content of various plant tissues has been presented earlier (Table 19-6). The true plant lipides may be classified as shown in Table 19-25. The terms fats and oils may be considered synonymous, referring only to the physical state of the lipides. Fats are those lipides which are solid at ordinary temperatures, while the oils are liquids under the same conditions.

The leaf and fruit lipides appear to function as protective coatings and apparently are not directly related to processes of intermediary metabolism. The seed fats and oils constitute a concentrated, high energy reserve which may be utilized to aid in maintaining the viability of the seeds over extended periods of time and to furnish the energy required for germination and sprouting of seedlings.

Fatty Acids. The fatty acids in plant products have been classified as shown in Table 19-26. Primary sources of some of the fatty acids are indicated in the last column of the table. Most of the fatty acids are found in the common oil-bearing seeds. However, some of the less common

TABLE 19-25. CLASSIFICATION OF PLANT LIPIDES

- 1.0. *Fats*—esters of fatty acids with glycerol
- 2.0. *Waxes*—esters of fatty acids with monohydric alcohols
 - 2.1. Simple aliphatic leaf waxes
 - 2.2. Alcohols and ketones related to fatty acids
- 3.0. *Phospholipides*—esters of fatty acids including phosphoric acid
 - 3.1. Esters with glycerol, lecithin, etc.
 - 3.2. Esters with carbohydrate alcohols
 - 3.3. Esters with inositol
- 4.0. *Derived Lipides*—hydrolysis products of the fats, waxes and phospholipids
 - 4.1. Fatty acids (palmitic, oleic, behenic, etc.)
 - 4.2. Alcohols
 - 4.2.1. Straight chain (cetyl, steryl, ceryl etc.)
 - 4.2.2. Sterols (phytosterols, sisosterol, stigmasterol)
 - 4.2.3. Hydrocarbons (carotenoids, pentacosane etc.)
 - 4.2.4. Oil soluble vitamins (vitamin D, E and K)

fatty acids are found only as constituents of leaf and fruit waxes. The approximate fatty acid composition of some common seed oils is presented in Table 19-27. It may be seen that the ratio of unsaturated to saturated fatty acids in all of these seed oils is equal to or greater than 3 to 1 and may be as high as 10 to 1. The unsaponifiable fractions generally constitute less than 2 per cent of the total fatty acids. The fatty acid composition of the seed fats and oils is more variable than the leaf and fruit fats, although certain regularities in composition follow phylogenetic lines. The leaf fats usually contain small amounts of saturated fatty acids (10 to 12 per cent) and oleic acid (15 to 30 per cent) and major proportions of either linoleic (30 to 50 per cent) or linolenic (20 to 40 per cent) acids. The fruit fats generally contain palmitic and oleic acids as major components with linoleic, stearic and myristic acids present in successively smaller proportions respectively. Some outstanding plant sources of myristic, palmitic, stearic, oleic, linoleic and linolenic acids are shown in Table 19-28.

The “drying” quality of vegetable fats and oils is related to the amounts and types of the constituent fatty acids. Oils having an iodine number of about 130 or greater are generally considered to be “drying oils.” iodine numbers between 100 and 130 characterize many of the “semidrying oils,” while the “nondrying oils” have iodine numbers falling below 100. The “drying” quality of various vegetable fats and oils is presented in Table 19-29.

Waxes. The “true” waxes are esters of the higher fatty acids (palmitic, stearic, oleic, etc.) and straight chain, higher monohydric alcohols (cetyl, steryl, octadecyl, etc.). Most of the waxes have high melting points and are difficult to hydrolyze. Fatty acid esters of sterols, provitamin A and provitamin D are also classified under the waxes. Crude waxes obtained from various plant tissues contain fatty acids, sterols, terpenes and hydro-

TABLE 19-26. CLASSIFICATION OF THE FATTY ACIDS DERIVED
FROM PLANT SOURCES

Classification	Acid	Chemical formula	Principal sources
1.0. <i>Saturated</i>			
1.1. Straight chain	Caproic	$C_6H_{12}O_2$	Coconut oil (0.5%), palm nut oil (0.5%)
	Caprylic	$C_8H_{16}O_2$	Coconut oil (8%)
	Capric	$C_{10}H_{20}O_2$	Coconut oil (7%)
	Lauric	$C_{12}H_{24}O_2$	Cinnamon oil (95%), palm oil (50%)
	Myristic	$C_{14}H_{28}O_2$	Nutmeg oil (76%), coconut oil (17%)
	Palmitic	$C_{16}H_{32}O_2$	Palm oil (42%), phulwara butter (56%)
	Stearic	$C_{18}H_{36}O_2$	Cocoa butter (35%), gurgi nut oil (45%)
	Arachidic	$C_{20}H_{40}O_2$	Peanut oil (4%)
	Behenic	$C_{22}H_{44}O_2$	Oil of ben
	Lignoceric	$C_{24}H_{48}O_2$	Arachis oil
	Cerotic	$C_{26}H_{52}O_2$	Opium wax
	Montanic	$C_{28}H_{56}O_2$	Montan wax
	Melissic	$C_{30}H_{60}O_2$	Carnauba wax
1.2. Branched chain	None		
2.0. <i>Unsaturated</i>			
2.1. Monoethenoid	Crotonic	$C_4H_6O_2$	Croton oil
	Tiglic	$C_6H_8O_2$	Croton oil
	Oleic	$C_{18}H_{34}O_2$	Filbert nut oil (91%), olive, teaseed oils (83%)
	Petroselinic	$C_{18}H_{34}O_2$	Seed of <i>Umbelliferae</i>
	Erucic	$C_{22}H_{42}O_2$	Rapeseed oil
2.2. Diethenoid	Linoleic	$C_{18}H_{32}O_2$	Walnut oil (73%), blackberry seed oil (80%)
2.3. Triethanoid	Linolenic	$C_{18}H_{30}O_2$	Linseed oil (50%), perilla seed oil (45%)
	Eleostearic	$C_{18}H_{30}O_2$	Chinese wood oil, tung oil (80%)
2.4. Polyethenoid	Parinaric	$C_{18}H_{28}O_2$	Seed oil of <i>Parinarium laurinum</i>
2.5. Monoethinoid		$C_{18}H_{32}O_2$	Fats of <i>Picramnia</i> sp.
3.0. <i>Hydroxy Fatty acids</i>			
3.1. Saturated, monohydroxy	Sabinic	$C_{12}H_{24}O_3$	Conifer wax
	Juniperic	$C_{16}H_{32}O_3$	Conifer wax
3.2. Unsaturated, monohydroxy	Ricinoleic	$C_{18}H_{34}O_3$	Castor oil (87%)
3.3. Saturated, dihydroxy	Dihydroxystearic	$C_{18}H_{36}O_4$	Castor oil

TABLE 19-26.—*Continued*

Classification	Acid	Chemical formula	Principal sources
4.0. <i>Keto acids</i>	Licanic	$C_{18}H_{30}O_3$	Oiticica (78%), <i>Rosaceae</i> seed fats
5.0. <i>Saturated, dibasic</i>	Thapsic Japanic	$C_{16}H_{30}O_4$ $C_{21}H_{40}O_4$	Conifer wax Japan wax
6.0. <i>Chaulmoogric series</i> Cyclic, one double bond	Aleprolic Aleprestic Alepylic Alepric Hydrocarpic Chaulmoogric	$C_6H_8O_2$ $C_{10}H_{16}O_2$ $C_{12}H_{20}O_2$ $C_{14}H_{24}O_2$ $C_{16}H_{28}O_2$ $C_{18}H_{32}O_2$	Chaulmoogra oil Chaulmoogra oil Chaulmoogra oil Chaulmoogra oil Chaulmoogra oil Chaulmoogra oil

carbons as shown in Table 19-30. Some commercially important plant waxes are listed in Table 19-31.

The plant waxes serve as protective coatings on seeds, stems, leaves, flowers and fruits. It has been suggested that they also reduce moisture loss by transpiration. Waxes may be secreted over the entire plant as protection from water or saline solutions. Where the sun's rays are particularly intense, the resins as well as the waxes act as protective mechanisms. In leaves, the greatest development of wax is on the under surface where the stomata are most abundant. The cuticles of fruits and vegetables contain observable amounts of waxes, as on grapes and plums, commonly referred to as the "bloom." Waxes may also occur dispersed in the cell in the same manner as fats and oils. However, the waxes do not appear to be utilized after they have been formed and are regarded as end products rather than intermediary metabolites.

Sterols. The sterols in higher plants (phanerogams) are generally classified as phytosterols, differentiating them from lower plant (cryptogams) sterols termed mycosterols. Plant sterols occur in the free state as well as in combination with fatty acids as esters, in which case they are considered to be waxes. Sterols show a marked tendency to separate as mixed crystals with closely related compounds. Many sterols are precipitated by the saponin, digitonin, with which they form an insoluble complex.

The occurrence of various phytosterols in plant tissues is shown in Table 19-32. Because it is a precursor of vitamin D, ergosterol assumes some importance as a plant sterol. Cottonseed oil contains 7.5 to 25 per cent of the sterols as ergosterol. It is also present in corn, peanut and linseed oils. The sitosterols are the most widely distributed of the phytosterols, occur-

TABLE 19-27. APPROXIMATE FATTY ACID COMPOSITION OF LIPIDES FROM PLANT SOURCES

Fatty acid constants		Fatty acids															Olive
Acid number	Boiling point (°C at 10 mm)	Melting point (°C)	Peanut	Soybean	Rice	Corn	Cotton-seed	Sesame	Sun-flower	Walnut	Flax-seed (lin-seed)	Buck-wheat leaf meal	Rye grass	Spin-ach	Avo-cado		
			%	%	%	%	%	%	%	%	%	%	%	%	%	%	
Saturated fatty acids																	
246	190	53.8	21	14	22	11	25	13	8	7	11	24	12		8	11	
219	210	62.9		0.1	0.4		0.4			0.4	0.2					1	
197.5	226	69.9	7	8	17	7	22	8	4	5	6	16			7	10	
179	240	75.2	5	5	3	3	2	4	3	1.5	4	6			1	1	
164.5	257	80.2	4	0.7	0.4	0.5	0.2	0.5	0.6	0.1	0.5	1.5					
152	272	84.2	2			.2	.3	.1	.4		.1	0					
			3		1			.1	.4			Trace					
Unsaturated fatty acids																	
248		-1.5	81	87	74	88	77	87	92	94	90	75	88	100	92	88	
221			Trace	0.1													
198.5	14			0.2	46	46	29	47	33	18	21	27	22	30	81	80	
200	-11		60	29	28	42	46	40	59	67	20	17	26	50	11	8	
201	-30		21	53			2			9	49	31	40	20			
				5													
Unsaponifiable fraction			0.5	1.0		1.5	1.5	0.9	1.3	0.5							
Total			102	102	96	101	104	101	101	102	101	99					
Iodine number			92	131	100	118	108	110	131	157	184	163					
Saponification number			191	192	188	190	195	191	192	193	192						
Melting point (°C)			-2	-22		-11	0	-2	-17	-14	-20						
Titer (°C)			29	20	27	17	34	22	18	15	20						
Analytical constants																	

TABLE 19-28. PRINCIPAL PLANT SOURCES OF SOME COMMON FATTY ACIDS

Myristic acid	%	Palmitic acid	%	Stearic acid	%	Oleic acid	%	Linoleic acid	%	Linolenic acid	%
Coconut oil.	17	Pulwara		Kokum		Filbert nut		Blackberry		Linseed	
Babassu oil.	17	butter...	56	butter...	56	oil.....	91	seed oil...	80	oil.....	49
Palm ker-		Palm oil..	42	Kanya		Olive oil...	83	Safflower		Perilla	
nel oil....	15	Okra seed		butter...	46	Teaseed oil.	83	seed oil...	78	seed oil.	45
Tung oil....	7	oil.....	26	Gurgi nut		Beechnut oil	81	Grapeseed		Buck-	
				oil.....	45	Pecan nut		oil.....	71	wheat	
		Cocoa				oil.....	79	Walnut oil..	67	leaf meal	
		butter...	24	Borneo						oil.....	31
		Cotton-		tallow...	40	Plum kernel		Passion fruit		Hemp-	
		seed oil.	21	Cocoa		oil.....	69	oil.....	62	seed oil.	25
				butter...	35	Peanut oil..	60	Sunflower		Rubber	
								seed oil...	58	seed oil.	20
										Walnut oil.	9

TABLE 19-29. "DRYING" QUALITY OF VARIOUS PLANT OILS

Drying oils		Semidrying oils		Nondrying oils	
Source	Iodine number	Source	Iodine number	Source	Iodine number
Linseed	184	Soybean	131	Peanut	92
Hempseed	165	Corn	118	Castor	85
Walnut	157	Cottonseed	108	Olive	85
Poppyseed	135	Rapeseed	100	Coconut	10
Sunflower seed	131	Mustard seed	100		

ring as the α , β , γ , δ , and ϵ isomers in various plant species. Stigmasterol frequently occurs with the sitosterols and is second in importance of the higher plant sterols. Both sitosterol and stigmasterol are also present in the waxes obtained from fruits, leaves, roots and stems as indicated in Table 19-30.

Vitamins

The plant kingdom is the primary source of vitamins. Although animal organisms may store large amounts of the vitamins within their tissues, this diverse group of compounds is apparently not synthesized to any significant extent by animal tissues. Vitamins perform specific and vital functions and are required for the transformation of energy and the regulation of both plant and animal metabolism. Certain vitamins function as prosthetic groups in enzyme systems that control respiration and intercellular metabolism. Other vitamins have special functions not directly related to intermediary metabolism. The vitamins are a relatively labile group of compounds, being inactivated readily by oxidation, heat, light and other physical and chemical agents.

TABLE 19-30. SOME CONSTITUENTS OF VARIOUS CRUDE PLANT WAXES

Tissue	Plant source	Constituents													Others
		Ursolic acid	Oleic acid	Linoleic acid	Linolenic acid	Ceryl alcohol	Myricyl esters	Sitosterol	Stigmasterol	Phytosterols	n-octacosanol	n-nonacosanol	n-nonacosane	Hentriacontane	
Seed	Corn						+	+	+					+	
Root	Dandi-lion							+	+						Carnaubyl Cerotate
Stem	Candelilla						+	+						+	+
Leaf	Sugar cane						+	+	+	+				+	{ Palmitic acid Myricyl alcohol Myricyl alcohol Ceryl esters
	Palm (car-nauba)					+	+								
Fruit	Apple	+									+	+	+		Lignoceryl alcohol
	Pear	+				+							+		
	Cherry	+	+	+									+		Umbelliferone
	Cranberry	+	+	+	+								+	+	
	Grapefruit		+	+	+					+			+	+	

The vitamin contents of 29 edible plant products, representing various plant tissues, are presented in Table 19-33.

Insufficient reliable quantitative data are available to permit satisfactory correlations between plant tissue types and vitamin content. However, a few generalizations are apparent. The edible flowers and green leaves contain relatively large amounts of all vitamins known to be essential for animal organisms. For the most part, the seeds are poor sources of most of the vitamins with the exceptions of thiamine and niacin. With a few individual exceptions, the roots, petioles, fruits and tubers are not outstanding sources of vitamins.

Ascorbic Acid. On a moisture-free basis, largest amounts of ascorbic acid are found in the green flowers, leaves, stems and in fruits having yellow or red colored flesh. The seeds contain relatively small quantities of ascorbic acid. However, the green or yellow colored seeds, such as pea and corn, have larger amounts of this vitamin than the nuts and other less highly colored seeds. The ascorbic acid content of plant tissues appears to be related to their vitamin A content. Some outstanding sources of ascorbic acid among the edible plant tissues are shown in Table 19-34.

Niacin. The niacin content of the plant products listed in Table 19-33 appears to vary widely and no correlation is apparent between the niacin content and particular types of tissues, i.e., roots, stems, etc. Food products containing unusually large amounts of niacin, calculated to a moisture-free basis, are listed in Table 19-35.

TABLE 19-31. SOME WAXES OBTAINED FROM PLANT TISSUES

Tissue	Plant source		Wax	Iodine no.	Saponi- fication no.	Melting range (°C)
	Common name	Generic name				
Leaf	Palm	<i>Copernicia cerifera</i>	Carnauba wax	7-14	79-95	78-84
	Attalea palm	<i>Scheelia martiana</i>	Ouricuri wax	17	110	87
	Sugar cane	<i>Saccharum of- ficinarum</i> L.	Cane wax			82
Stem	Candelilla	<i>Pedilanthus pavo- nis</i>	Candelilla wax	13-37	46-67	64-71
	Rhimba tree	<i>Euphorbia steno- clada</i>	Madagascar wax			88
Bark	Douglas fir	<i>Pseudotsuga taxi- folia</i>	Douglas fir wax			63
Fruit		<i>Toxicodendron succedaneum</i>	Japan wax	4-13	207-238	41-51
	Apple (cuti- cle)	<i>Malus pumila</i>	Apple cuticle wax			80
Seed	Sunflower	<i>Helianthus an- nuus</i>	Sunflower seed wax			
	Goat nut	<i>Simmondsia chi- nensis</i> (cali- fornica)	Jajoba wax	82	92	

TABLE 19-32. OCCURRENCE OF STEROLS IN PLANT TISSUES

Sterol		Principal sources
Name	Chemical formula	
Campesterol.....	C ₂₈ H ₄₈ O	Rapeseed, soybean, and wheat germ oils
Brassicasterol.....	C ₂₈ H ₄₆ O	Oil of turnip, rapeseed oil
Spinasterol (α, β, γ)....	C ₂₉ H ₄₈ O	Spinach and cabbage fats, alfalfa seed oil, seneca snake-root oil
Stigmasterol.....	C ₂₉ H ₄₈ O	Oils of kidney bean, calabar bean, soybean, rice bran, corn, coconut
Sitosterols.....	C ₂₉ H ₅₀ O	Koryan corn oil, wheat and rye germ oils
α-Sitosterol.....		Rye germ oils
β-Sitosterols.....		Cottonseed oil, seed oil of <i>Calycanthus floridus</i> , kidney bean oil
γ-Sitosterol.....		Soybean oil, wheat germ oil
Dihydrositosterol.....	C ₂₉ H ₅₁ OH	Tall oil, oils of corn, wheat, rice and rye.

TABLE 19-33. APPROXIMATE VITAMIN CONTENT OF VARIOUS EDIBLE PLANT PRODUCTS
(Calculated to a moisture-free basis)

Vitamin	Units per 100 g. dry weight	Seed										Stem	Petiole		Leaf			Flower		Fruit							Tuber				
		Cereal				Legume				Nut			Carrot	Red beet	Soybean	Asparagus	Celery	Rhubarb	Cabbage	Lettuce	Spinach	Broccoli	Cauliflower	Orange	Apple	Grape		Strawberry	Tomato	Summer squash	Avocado
		Wheat	Corn	Rice		Pea	Bean	Soybean	Peanut	Almond	Pecan																					Walnut
Ascorbic acid...	mg	0	46	0	100	2	35	6	Trace	2	3	80	—	100	470	110	175	650	150	800	1200	850	400	30	20	600	400	350	50	75	
Biotin.....	μgm	6	—	—	8	—	66	35	—	—	—	17	—	—	—	—	—	—	30	—	—	—	16	—	—	—	—	—	—	—	
Choline.....	mg	—	—	—	—	—	380	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	100	—	—	—	—	—	—	—	
Folic acid.....	μgm	60	—	—	120	—	—	290	—	—	210	90	—	—	—	—	—	130	—	2500	—	—	24	—	—	—	170	—	—	50	
Inositol.....	mg	—	—	—	—	—	—	185	—	—	—	—	—	—	—	—	—	—	—	—	—	1200	—	—	—	—	—	—	—	—	
Niacin.....	mg	5	6	5	10	2	3	14	5	1	1	4	3	6	20	6	2	4	4	8	11	7	2	1	1	3	8	15	3	5	
Pantothenic acid.....	mg	2	3	2	2	—	2	3	—	—	—	2	—	—	—	—	—	2	—	10	—	—	1	0.3	—	—	6	—	—	2	
Para-amino-benzoic acid.	μgm	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	32	—	—	—	—	—	—	—	—	
Pyridoxine.....	μgm	500	1200	200	—	—	1300	300	—	—	1000	1600	—	—	—	—	—	3800	1100	—	—	—	40	200	—	—	1200	—	—	720	
Riboflavin.....	μgm	100	450	60	620	260	330	230	700	130	140	500	400	1500	2700	630	—	650	1500	2100	1200	40	200	220	700	1800	400	180	180	180	
Thiamine.....	μgm	650	1200	360	1300	750	1100	1100	260	740	380	500	150	1700	2300	800	—	800	800	1500	1000	1300	800	250	330	300	1000	1000	170	450	
Vitamin A.....	I.U.	22	1600	0	2600	0	120	25	0	50	30	102,000	160	1300	14,000	0	600	1100	10,000	130,000	35,000	1100	2400	550	450	600	19,000	5000	850	90	
Vitamin B ₁₂	μgm	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
Vitamin E.....	mg	—	390	—	—	—	180	25	—	40	—	4300	—	—	—	—	—	—	—	—	—	800	—	—	—	—	—	—	—	—	
Vitamin K.....	μgm	—	70	—	—	—	—	—	—	—	—	45	—	—	—	—	—	420	2400	—	280	—	—	—	—	60	200	—	20	40	

TABLE 19-34. SOME OUTSTANDING SOURCES OF ASCORBIC ACID AMONG EDIBLE PLANT PRODUCTS

(Calculated to a moisture-free basis)

Plant	Tissue	Ascorbic acid (mg/100 g)
Guava.....	Fruit	1550
Currants, black.....	Fruit	1300
Broccoli.....	Flower	1200
Kale.....	Leaf	970
Watercress.....	Leaf	940
Parsley.....	Leaf	930
Cauliflower.....	Flower	850
Spinach.....	Leaf	800
Cabbage.....	Leaf	650
Brussel sprouts.....	Leaf	650
Strawberry.....	Fruit	600
Asparagus.....	Stem	470
Orange.....	Fruit, juice	400

TABLE 19-35. SOME OUTSTANDING SOURCES OF NIACIN AMONG VARIOUS EDIBLE PLANT PRODUCTS

(Calculated to a moisture-free basis)

Plant	Tissue	Niacin (mg/100 g)
Asparagus.....	Stem	20
Squash, summer.....	Fruit	15
Peanut.....	Seed	14
Watercress.....	Leaf	12
Broccoli.....	Flower	10
Pea, green.....	Seed	10
Apricot.....	Fruit	9
Cantaloup.....	Fruit	8
Corn, raw.....	Seed	6
Rice.....	Seed	5
Wheat.....	Seed germ	5
Almond.....	Seed	5

Riboflavin. On a moisture-free basis, the edible leaves and flowers contain the largest quantities of riboflavin as shown in Table 19-33. Within each class of tissues (roots, stems, etc.) the riboflavin content of individual plant products appears to be related to the amounts of yellow and green pigments present in the tissue. Some outstanding sources of riboflavin among the higher plant tissues are shown in Table 19-36. It is of interest that on a moisture-free basis many of the edible plant tissues contain more riboflavin than whole milk which contains about 1.3 mg/100 g of riboflavin and which is considered to be an excellent source of this vitamin for animal organisms.

Thiamine. The nut seeds and deciduous fruits contain less than 1 milli-

TABLE 19-36. SOME OUTSTANDING SOURCES OF RIBOFLAVIN AMONG EDIBLE PLANT PRODUCTS
(Calculated to a moisture-free basis)

Plant	Tissue	Riboflavin (mg/100 g)
Turnip.....	Leaf	4.4
Spinach.....	Leaf	2.7
Asparagus.....	Stem	2.7
Watercress.....	Leaf	2.5
Mustard.....	Leaf	2.5
Broccoli.....	Flower	2.1
Chard.....	Leaf	2.0
Squash, summer.....	Fruit	1.8
Lettuce.....	Leaf	1.5
Soybean.....	Sprouts	1.5
Cauliflower.....	Flower	1.2
Brussel sprouts.....	Leaf	1.1

gram per cent of thiamine on a moisture-free basis. The green leaves, flowers, vegetable fruits and legume seeds may contain up to three times that amount. By comparison, beef liver, generally considered to be an excellent source of B vitamins, contains slightly less than 1 milligram per cent of thiamine. Some plant products containing relatively large amounts of thiamine are shown in Table 19-37.

Vitamin A. Vitamin A is never found in plant tissues. However, several carotenoids and particularly some of the carotenes are termed provitamins A since they are precursors that may be converted to vitamin A by animal organisms. β -Carotene, containing two moles of provitamin A, has the

TABLE 19-37. SOME OUTSTANDING SOURCES OF THIAMINE AMONG VARIOUS EDIBLE PLANT PRODUCTS
(Calculated to a moisture-free basis)

Plant	Tissue	Thiamine (mg/100 g)
Asparagus.....	Stem	2.3
Wheat.....	Seed germ	2.3
Soybean.....	Sprouts	1.7
Spinach.....	Leaf	1.5
Pea, green.....	Seed	1.5
Watercress.....	Leaf	1.3
Soybean.....	Seed	1.2
Tomato.....	Fruit	1.0
Broccoli.....	Flower	1.0
Squash, summer.....	Fruit	1.0
Kale.....	Leaf	0.9
Brussel sprouts.....	Leaf	.8
Wheat.....	Seed	.7
Rice.....	Seed	.4

TABLE 19-38. APPROXIMATE α - AND β -CAROTENE CONTENT OF VARIOUS PLANT LEAVES
(Calculated to a moisture-free basis)

Plant	Carotene ^a		
	Total (mg/100 g)	Alpha (mg/100 g)	Beta (mg/100 g)
Tomato.....	42	5	37
Squash, winter (Hubbard).....	22	Trace	22
Potato.....	15	1.5	13.5
Carrot.....	14.5	8.5	6
Lettuce.....	6	0	6
Apricot.....	4	0	4

^a One International Unit (I.U.) of Vitamin A is equivalent to approximately 0.6 μ mg of β -carotene and 1.2 μ mg of α -carotene.

highest biological activity. α -Carotene and cryptoxanthin (a xanthophyll) each containing one mole of provitamin A, have about 50 per cent of the provitamin A activity of β -carotene. γ -Carotene has only about 25 per cent of the activity of β -carotene, while ζ -carotene is inactive as a vitamin A precursor.

β -Carotene occurs primarily in plants although it may also be found in some animal tissues. Both α - and β -carotene are widely distributed in plant tissues as shown in Tables 19-38 and 19-55. They occur in the lowest forms of plant life (bacteria) as well as the highest plant orders (dicotyledons). Green leaves and many orange colored fruits and roots contain relatively large amounts of provitamins A. Carrots are an outstanding source of α -carotene although significant quantities of both α - and β -carotene occur in tomato fruits.

Spinach and carrots are outstanding sources of provitamin A, containing more than 100,000 I.U. of vitamin A activity per 100 grams of moisture-free tissue, as shown in Table 19-39. Edible plants containing from 10,000 to 35,000 I.U. of vitamin A activity include broccoli, tomato, asparagus and lettuce. With the exception of the immature pea seed and corn, most seeds contain insignificant amounts of vitamin A activity, ranging from 0 in rice, bean and almond to 120 I.U. in soybeans. Most fruits contain between 500 and 5000 I.U. of vitamin A activity.

Vitamin D. Vitamin D is not found in higher plants although provitamin D occurs in a wide variety of higher plants in the form of ergosterol and 7-dehydrocholesterol. Provitamin D may be converted to biologically active vitamin D by irradiation with ultra violet light. The unsaponifiable, sterol fractions of solvent extracted plant tissues may contain relatively large amounts of provitamin D. The sterol fraction obtained from rye grass,

TABLE 19-39. SOME IMPORTANT SOURCES OF PROVITAMIN A AMONG EDIBLE PLANT TISSUES
(Calculated to a moisture-free basis)

Plant	Tissue	Vitamin A equivalent (I.U./100 g)
Spinach.....	Leaf	130,000
Carrot.....	Root	102,000
Chard.....	Leaf	92,000
Turnip.....	Leaf	91,000
Watercress.....	Leaf	75,000
Cantaloup.....	Fruit	57,000
Parsley.....	Leaf	51,000
Broccoli.....	Flower	35,000
Sweet potato.....	Root	24,000
Apricot.....	Fruit	19,000
Asparagus.....	Stem	14,000

TABLE 19-40. TOCOPHEROLS (VITAMIN E) IN VARIOUS VEGETABLE OILS

Plant Oil	Tissue	Tocopherols			
		Total (mg/100 g)	α (mg/100 g)	γ (mg/100 g)	δ (mg/100 g)
Carrot.....	Root	500		0	0
Wheat.....	Seed germ	274	192		
Soybean.....	Seed	168	20	98	50
Corn.....	Seed	102	13	89	
Rice.....	Seed bran	91	58	33	
Cotton.....	Seed	86	41	36	9
Okra.....	Seed	74	31	43	
Palm.....	Seed	56	30	26	
Castor bean.....	Seed	50			
Pecan.....	Seed	42	20	22	
Peanut.....	Seed	34	13	14	7

spinach, orchard grass, wheat germ oil and cabbage have been found to contain 1.5, 1.0, 0.8, 0.8, and 0.05 per cent of provitamin D, respectively.

Vitamin E (Tocopherols). Vitamin E occurs widely in seed oils as the free tocopherols as illustrated in Tables 19-33 and 19-40. The vegetable fats are the richest sources of vitamin E among the natural foods. As much as 1 per cent tocopherol has been found in a sample of rye germ oil. On a moisture-free basis, the green leafy vegetables contain more extractable tocopherols than wheat germ, a product generally recognized as an excellent source of this vitamin.

The tocopherols are natural antioxidants and tend to retard the development of rancidity in extracted plant fats.

Vitamin K. The active form of vitamin K in green leaves is 2-methyl-

TABLE 19-41. APPROXIMATE VITAMIN K ACTIVITY OF VARIOUS EDIBLE PLANT PRODUCTS

Plant	Tissue	Vitamin K activity (Dam units/100 g dry weight)
Spinach.....	Leaf	750,000
Cabbage.....	Leaf	720,000
Cauliflower.....	Flower	480,000
Tomato.....	Fruit	85,000
Potato.....	Tuber	9,000
Carrot.....	Root	8,500

3-phytyl-1,4-naphthaquinone often referred to as vitamin K₁. Vitamin K₂ or 2-methyl-3-difarnesyl-1,4-naphthaquinone is found mainly as a product of bacterial metabolism.

Vitamin K was first shown to be present in lettuce and later in hempseed, tomato fruit, kale, alfalfa, rice bran, cabbage, cauliflower and chestnut. The vitamin K content of various plant products is shown in Tables 19-33 and 19-41. It may be seen that spinach, cabbage and cauliflower are outstanding sources of vitamin K₁. Most other edible plants contain 10 per cent or less of the vitamin K activity found in spinach.

Minerals

A large proportion of the elements in the periodic table have been detected in the tissues of plants as indicated in Table 19-42, showing the mineral composition of several edible seeds. Many of the elements, serving widely diverse functions, are important catalysts in the processes of intermediary metabolism.

Calcium, phosphorus and iron are among the more important elements fulfilling vital functions in both plant and animal nutrition. The approximate calcium, phosphorus and iron content of 29 plant products, chosen from among the edible seeds, roots, sprouts, stems, petioles, leaves, flowers, fruits and tubers, are given in Table 19-43. On a moisture-free basis, the stems, petioles, leaves and flowers contain the largest amounts of all three elements. A few flowers and green leaves, including broccoli, cauliflower, spinach and watercress have unusually high levels of calcium, phosphorus and iron. The fruits, seeds and potato tuber contain relatively small amounts of these minerals. The white potato tuber and the cereal seeds are especially low in calcium, while several nut seeds and soybeans contain large amounts of phosphorus. Some outstanding sources of total calcium, phosphorus and iron among the edible plant tissues are listed in Tables 19-44, 19-45 and 19-46, respectively.

From the standpoint of animal nutrition, the total amount of each element in plants used for food may be less important than the percentage of ionizable or nutritionally available mineral. For example, the available

TABLE 19-42. INORGANIC CONSTITUENTS IN SOME EDIBLE SEEDS
(Calculated to a moisture-free basis)

Element	Wheat0 g) (mg/10	Corn (mg/100 g)	Rice (mg/100 g)	Peanut (mg/100 g)	Soybean (mg/100 g)
Aluminum.....	3	—	—	—	—
Arsenic.....	0.023	0.019	—	—	—
Barium.....	.80	.90	—	0.20	0.80
Boron.....	—	—	—	.26	1.9
Bromine.....	—	.17	—	—	—
Calcium.....	45	20	70	75	240
Chlorine.....	90	24	—	—	30
Chromium.....	—	—	—	15	—
Cobalt.....	0.0012	0.0011	0.0006	0.0003	—
Copper.....	.9	.8	.04	.015	0.12
Fluorine.....	—	—	.94	.002	—
Iodine.....	.0067	.018	.004	.0002	—
Iron.....	5	3	2	2	8
Magnesium.....	160	430	160	220	310
Molybdenum.....	—	—	—	2	—
Nickel.....	0.035	0.014	0.002	0.051	0.392
Phosphorus.....	420	350	450	460	700
Potassium.....	480	400	380	800	1800
Selenium.....	3	—	—	—	—
Sodium.....	70	50	100	—	240
Strontium.....	—	—	—	3	—
Sulphur.....	180	140	—	220	240
Tin.....	—	—	—	3	—
Titanium.....	0.09	0.140	—	0.56	—
Vanadium.....	—	—	—	30	—
Zinc.....	6.3	2.0	1.3	41	1.1

iron in plant tissues may range from 20 to 100 per cent of the total iron as indicated in Table 19-47. It may be seen that soybean sprouts contain about 45 per cent more total iron than figs. However, the latter has approximately 60 per cent more available iron than the soybean sprouts. Similarly both calcium and phosphorus are nutritionally unavailable when combined as calcium phytate in plant tissues. As much as 87 per cent of the phosphorus in severely heat processed soybean curd may be present as nutritionally unavailable phytin phosphorus. Phytic acid, oxalic and other organic acids may bind a major proportion of the calcium in plant tissues.

Tannins and Lignin

Tannins. Chemically, the tannins are polyhydroxyphenols or derivatives of polyhydroxyphenols which may be in complex condensed ring structures. They may be found in all types of higher plant tissues, including seeds, roots, stems, wood, bark, leaves and fruits and are usually present in regions of intense metabolic activity such as active leaves, galls and other

TABLE 19-43. APPROXIMATE CALCIUM, PHOSPHORUS AND IRON CONTENT
OF VARIOUS EDIBLE PLANT PRODUCTS
(Calculated to a moisture-free basis)

Tissue	Plant	Calcium (mg/100 g)	Phosphorus (mg/100 g)	Iron (mg/100 g)
Seed, cereal	Wheat	45	420	5
	Corn	20	450	3
	Rice	70	350	2
Seed, legume	Pea, green	85	470	7
	Bean, common	180	500	3
	Soybean	240	700	8
	Peanut	75	460	2
Seed, nut	Almond	260	500	5
	Pecan	75	330	3
	Walnut	90	390	2
Root	Carrot	330	320	7
	Beet, red	220	350	8
Sprout	Soybean	350	490	7
Stem	Asparagus	300	890	13
Petiole	Celery	800	640	8
	Rhubarb	1000	490	10
Leaf	Cabbage	610	410	7
	Lettuce	420	480	10
	Spinach	1100	750	41
Flower	Broccoli	1300	750	13
	Cauliflower	270	870	13
Fruit	Orange Juice	90	160	2
	Apple	40	60	2
	Grape	95	120	3
	Strawberry	270	260	8
	Tomato	180	460	10
	Squash, summer	300	300	8
	Avocado	290	110	2
Tuber	Potato, white	50	250	3

pathological growths on higher plants. A classification of the natural organic tannins is presented in Table 19-48.

Plant galls may contain from 25 to 75 per cent tannin and are a principal source of plant tannins of commerce. Tea leaves may contain up to

TABLE 19-44. PLANT PRODUCTS CONTAINING LARGE AMOUNTS OF TOTAL CALCIUM
(Calculated to a moisture-free basis)

Plant	Tissue	Calcium (mg/100 g)
Watercress.....	Leaf	3000
Mustard.....	Leaf	3000
Kale.....	Leaf	1700
Broccoli.....	Flower	1300
Endive.....	Leaf	1280
Parsley.....	Leaf	1200
Chard.....	Leaf	1160
Spinach.....	Leaf	1100
Rhubarb.....	Petiole	1000
Celery.....	Petiole	800
Cabbage.....	Leaf	610
Radish.....	Root	580

TABLE 19-45. PLANT PRODUCTS CONTAINING LARGE AMOUNTS OF TOTAL PHOSPHORUS
(Calculated to a moisture-free basis)

Plant	Tissue	Phosphorus (mg/100 g)
Mushroom.....	Edible flesh	1300
Wheat.....	Seed, germ	1200
Asparagus.....	Stem	890
Cauliflower.....	Flower	870
Endive.....	Leaf	830
Spinach.....	Leaf	750
Broccoli.....	Flower	750
Cocoa.....	Seed	740
Watercress.....	Leaf	720
Soybean.....	Seed	700
Brazil nut.....	Seed	650
Celery.....	Petiole	640
Almond.....	Seed	500
Rhubarb.....	Petiole	490

15 per cent tannin. Tannins are found in the wood, stems and bark of the oak and hemlock, unripe fruits such as the persimmon, pomegranate and plum, walnuts and seedcoats such as the peanut seedcoat.

Although it has been suggested that the tannins act as natural antioxidants and fungicides, their exact function in plant tissues is unknown.

Lignin. Chemically, lignin appears to be an amorphous polyflavanone varying in color between light yellow and brown after isolation. It is generally found in the secondary cell walls in the hard, inactive, mature tissues, such as wood, straw and corn cobs. Hop flowers and coniferous woods may contain more than 50 per cent lignin although most tissues contain less than 20 per cent lignin on a moisture-free basis as shown in Table 19-16.

TABLE 19-46. PLANT PRODUCTS CONTAINING LARGE AMOUNTS OF TOTAL IRON
(Calculated to a moisture-free basis)

Plant	Tissue	Iron (mg/100 g)
Spinach.....	Leaf	41
Mustard.....	Leaf	40
Watercress.....	Leaf + stem	31
Parsley.....	Leaf	27
Chard.....	Leaf	27
Endive.....	Leaf	25
Turnip.....	Leaf	23
Chinese cabbage.....	Leaf + petiole	20
Kale.....	Leaf	16
Radish.....	Root	15
Cocoa.....	Seed	14
Asparagus.....	Stem	13
Broccoli.....	Flower	13
Cauliflower.....	Flower	13
Tomato.....	Fruit	10

TABLE 19-47. AVAILABLE IRON IN VARIOUS PLANT PRODUCTS
(Calculated to a moisture-free basis)

Plant	Tissue	Iron		
		Total (mg/100 g)	Available	
			Per cent	Amount (mg/100 g)
Currant, black.....	Fruit	8.3	100	8.3
Fig.....	Fruit	5.5	96	5.3
Cocoa.....	Seed	14.3	93	13.3
Onion.....	Bulb	6.2	87	5.4
Soybean.....	Seed	8.5	84	7.1
Bean, haricot.....	Seed	6.7	83	5.6
Lentil.....	Seed	8.2	66	5.4
Potato, white.....	Tuber	3.2	55	1.7
Rice.....	Seed	2.3	45	1.0
Peanut.....	Seed	2.0	45	0.9
Soybean.....	Sprout	7.3	45	3.3
Blackberry.....	Fruit	5.7	40	2.3
Spinach.....	Leaf	41	22	9.0

Although lignin occurs widely among higher plant tissues, its function has not been established and it has no known nutritional value for higher animals. Sulfonated lignin, a by-product of the paper-making industry, may be hydrolyzed with hot alkali to yield the well-known flavoring agent, vanillin.

TABLE 19-48. CLASSIFICATION OF NATURAL ORGANIC TANNINS

- I. *Condensed Tannins* (contain phloroglucinol nucleus, e.g., quebracho)
 - A. Catechin tannins (rhubarb, cocoa bean)
 - 1. Acacatechin tannins
 - 2. Isoacatechin tannins
 - 3. Gambir catechin
 - B. Maclurin tannins (contains maclurin nucleus)
- II. *Hydrolyzable Tannins*
 - A. Gallotannins (yield gallic or m-digallic acids, e.g., Chinese nutgalls)
 - B. Ellagitannins (yield ellagic acid, e.g., Chestnut wood)
 - C. Cafetannins (yield caffeic and quinic acids, e.g., coffee)
- III. *Unclassified*

Flavonoids

Flavonoids have been broadly defined as organic compounds possessing the carbon framework of a flavone, or more broadly as $C_6-C_3-C_6$ compounds. The latter definition includes flavonols, flavones, benzalcoumaranones, flavononols, flavanones, chalcones, anthocyanidins, dihydrochalcones and catechins. Members of this class of compounds are found universally among higher plants. Over 200 compounds of this type have been characterized chemically.

Since the catechins and lignin have been discussed previously, it will be sufficient for the present purposes to refer only to the 2-phenylchromones (2-phenyl-benzo- γ -pyrone), such as the flavones, flavanones, flavonols, often termed anthoxanthins, and the related oxonium salts or anthocyanins.

A majority of the water-soluble blue, red and yellow colors in higher plant tissues are due to the presence of anthocyanin and anthoxanthin compounds. Flavonoids, being water-soluble, are present primarily in the vacuolar sap. The carotenoid pigments, such as lycopene, are water-insoluble and are found in particulate form in the cytoplasm.

The biological significance of flavonoids in higher plant tissues is obscure. It has been suggested that glucose in combination with flavonoid glycosides forms a soluble, easily hydrolyzable complex, and is thus temporarily inactivated until it is brought to that portion of the plant where the glucose is stored or utilized for metabolic purposes. It has also been postulated that flavonoid compounds are the precursors or intermediary metabolites in the formation of the anthocyanidin pigments. Flavonoid compounds might conceivably act as light filters to regulate photosynthesis or they may play a role as components of oxidation-reduction systems. The anthoxanthins and the anthocyanins appear to be derived from common precursors, the biogenesis of each flavonoid being regulated by genetic mechanisms.

Anthoxanthins. The anthoxanthins are almost ubiquitously distributed in one or more tissues of higher plants including seeds, stems, bark, leaves, flowers and fruits as illustrated in Table 19-49. They range in color from

TABLE 19-49. FLAVONOID AND CARBOHYDRATE MOIETIES IN SOME NATURALLY OCCURRING ANTHOXANTHINS

Anthoxanthin = Flavonoid nucleus + Carbohydrate moiety			Plant	Tissue
Toringin	Flavone	7-Glucoside	<i>Pinus toringo</i>	Bark
Cosmetin	Apigenin (flavone)	7-Glucoside	<i>Euphorbia thymifolia</i>	Stem, leaf
Galuteolin	Luteolin (flavone)	5-Glucoside	<i>Galega officinalis</i>	Seed
Kaempferitrin	Kaempferol (flavonol)	3-Rhamnoside	<i>Indigofera arrecta</i>	Leaf
Hyperin	Quercetin (flavanol)	3-Galactoside	Jonathan apple	Fruit
Rutin	Quercetin (flavanol)	3-Rhamnoglucoside	Buckwheat	Leaf
Naringin	Naringenin (flavanone)	7-Rhamnoglucoside	Grapefruit	Fruit rind, juice
Butrin	Butin (flavanone)	3,7-Diglucoside	<i>Butea frondosa</i>	Flower
Hesperidin	Hesperitin (flavanone)	7-Rhamnoglucoside	Orange	Fruit rind, juice

white to orange in the pure form and may occur free in nature or in combination with simple sugars as glycosides.

The anthoxanthins in citrus have been studied extensively, possibly because of the suggestion that citrus fruits may contain a biologically active flavonoid often referred to as vitamin P. Some flavones, flavonols and flavanones present in the tissues of various citrus varieties are listed in Table 19-50.

Anthocyanins. Anthocyanin pigments are composed of an anthocyanidin nucleus coupled with one or more simple sugars. The anthocyanidin nuclei are all derivatives of 2-phenylbenzopyrylium salts and are related to the reduced forms of some of the anthoxanthins. The carbohydrate moiety is often glucose attached to the anthocyanidin at the 3 or 5 positions as described in Table 19-51.

The anthocyanidins change color as a function of the hydrogen ion concentration and may be employed as acid-base indicators. In general the acid salts are red and basic salts are blue in aqueous solution. The chemical structure of the anthocyanidin affects its color markedly. In general, anthocyanidins containing one phenolic hydroxyl group are redder than those with 2 or more hydroxyl groups. The diglucosides are generally bluer than the monoglucosides. Methylation of hydroxyl groups tend to increase redness. The anthocyanin pigments have wide distribution among higher plants as indicated in Table 19-51. However, these compounds have no

TABLE 19-50. SOME ANTHOXANTHINS IN CITRUS

Anthoxanthin	Flavonoid nucleus	Source	Tissue
Nobiletin Ponkanetin Rhoifolin	Flavone	Mandarin Tangerine Sour orange	Fruit Fruit Ripe fruit
Rutin	Flavanol	Orange-grapefruit hybrid	Fruit rind
Tangeretin		King Mandarin	Fruit rind, oil
Citronetin Citronin Hesperitin Hesperidin	Flavanone	Ponderosa lemon <i>Citrus limon</i> <i>Citrus aurantium</i> Sweet orange	Fruit rind Fruit rind Fruit rind Twigs, leaves, fruit rind and juice
Naringenin Naringin		Shaddock Grapefruit	Fruit rind, flowers Flowers, fruit rind and juice
Neohesperidin Poncirin		Trifoliate orange Trifoliate orange	Unripe fruit Flowers, fruit

known nutritional significance for animals and their specific role in the intermediary metabolism of plant tissues has not been elucidated.

Heterocyclic Compounds

Purines. Purines are widely distributed in plant tissues. However, they are generally present in exceedingly small concentrations. The most important plant purines are adenine, guanine, xanthine and hypoxanthine. Guanine and adenine have been found as constituents of nucleic acids as well as in the free state. In the latter form they have been observed in seeds (pea, coffee), roots (sugar beet), tubers (potato) and leaves (alfalfa, tea), and many other plant tissues. Xanthine and hypoxanthine occur largely in the free state and have been reported in seeds, seedlings, leaves and fruits. Uric acid, a derivative of purine, has been found in leaves and seeds in concentrations up to 250 milligrams per kilogram of tissue.

The metabolic roles of uric acid, xanthine and hypoxanthine in plant tissues are unknown. Adenine is important as a constituent of nucleic acids as well as of nucleotides which function as coenzymes in oxidative processes. Adenine riboside polyphosphates have important functions as donors or receptors of phosphate in processes of intermediary metabolism. Certain purines act as growth regulating substances in both higher and lower plants. The capacity for purine synthesis appears to be characteristic of specific plant tissues from which the purines are translocated to perform vital functions necessary for normal growth of the whole plant.

The methylated purines may be considered as alkaloids and are discussed under that heading.

TABLE 19-51. ANTHOCYANIDIN AND CARBOHYDRATE MOIETIES IN SOME NATURALLY OCCURRING ANTHOCYANINS

Anthocyanin	= Anthocyanidin nucleus	+ Carbohydrate moiety	Sources
Chrysanthemin	Cyanidin	3-Glucoside	Scarlet winter aster, red autumnal foliage of <i>Acer circumbatum</i>
Cyanin		3,5-Diglucoside	Red rose, blue corn flower (<i>Centaurea</i>)
Idaein		3-Galactoside	Skin of Jonathan apple, cranberry fruit, leaves of <i>Fagus sylvatica</i>
Keracyanin		3-Rhamnoglucoside	Ripe olives, black cherry
Mecocyanin		3-Gentiobioside	<i>Papaver rhoeas</i>
Delphinin	Delphinidin	Dibenzoyldiglycoside	Delphinium (flowers)
Hyacin		Diglucoside	<i>Hyacinthus orientalis</i> (Liliaceae)
Gesnerin	Gesneridin	5-Glucoside	<i>Gesnera fulgens</i>
Hirsutin	Hirsutidin	3,5-Diglucoside	<i>Primula hirsuta</i>
Oenin	Malvidin	3-Glucoside	Skin of black grapes
Malvin		3,5-Diglucoside	<i>Malva silvestris</i> , <i>Primula viscosa</i>
Callistephin	Pelargonidin	3-Glucoside	<i>Calistephus chinensis</i>
Pelargonin		3,5-Diglucoside	Scarlet pelargonium (flower)
Oxycoccicyanin	Peonidin	3-Glucoside	<i>Oxycoccus macrocarpus</i>
Peonin		3,5-Diglucoside	Red peony (flower)
Petunin	Petunidin	3,5-Diglucoside	Muscadine grapes

Pyrimidines. Pyrimidines, like the purines, are found in all higher plants at very low concentrations. Cytosine, the principal pyrimidine found in higher plant tissues, occurs in the ribonucleic acids of plant viruses, wheat, rye and pea seeds. The intermediary metabolism of the pyrimidines in higher plants is not well understood.

Alkaloids. Very large numbers of heterocyclic nitrogenous bases or alkaloids have been isolated from various tissues of miscellaneous higher plants and tested for pharmaceutical purposes. However, relatively few members of this class of compounds are present in commercially produced agricultural plant commodities. The principal alkaloids present in common

plants are the methylated purines, present in many species, and nicotine, the primary alkaloid of tobacco.

The functions and biogenesis of the alkaloids in higher plants are not known. It has been suggested that alkaloids may be excretion products. However, since they are known to be synthesized under conditions of limited nitrogen availability, it would appear more likely that the alkaloids have important, but unknown functions in intermediary metabolism.

Methylated Purines. Caffeine, theobromine, heteroxanthine and theophylline are the principal methylated purines found in the tissues of higher plants. They may be considered as derivatives of the purine, xanthine. However, the biogenetic relationship between xanthine and the methylated purines has not been described completely.

Heteroxanthine and theophylline have been found only in sugar beets and tea leaves, respectively. Caffeine and theobromine are more widely distributed, being found in the seeds and leaves of many higher plants. Caffeine is present in coffee, tea, cocoa and maté, while cola and cocoa are prominent sources of theobromine. These alkaloids are always found in the leaves and are usually absent in the roots and wood. Varying amounts occur in the flowers and fruits. On a moisture-free basis, highest methylated purine concentrations are found in young leaves, increasing in total amount but decreasing in percentage as the leaves mature, and decreasing in both total amount and total percentage toward senescence.

Nicotine. Nicotine is found primarily in the leaf of *Nicotiana tabacum*. It is synthesized in the roots and translocated to the leaves through the xylem rather than through the phloem, which transports most other plant constituents. Amino acids are the probable precursors of nicotine which is stable in leaf tissue and does not appear to be a reserve source of metabolic nitrogen.

In addition to nicotine, some varieties of *Nicotiana* contain the chemically related alkaloids nornicotine and anabasine. Nornicotine is not physiologically active. However, both nicotine and anabasine are highly toxic stimulants of the central nervous system in higher animals.

Chlorophyll. Of the various forms of chlorophyll known to exist in green plants, the most important of these are chlorophylls a and b, the green coloring matter in all higher plants and most lower plants that perform photosynthesis. Chlorophylls c and d are found predominantly in oceanic flora, bilins and certain forms of bacteria.

The synthesis of chlorophyll in most higher plants is a function of light energy, although chlorophyll production may proceed to some extent in the dark in conifer seedlings, algae and bryophytes. Even in these instances light accelerates the rate of chlorophyll synthesis. Light absorbed by the chlorophyll itself promotes the destruction of the chlorophyll through

oxidative mechanisms involving the uptake of oxygen. The destruction of chlorophyll and the loss of green color unmasks the carotenoid and flavanoid pigments which appear to develop at various stages of maturity in leaves, flowers and fruits. The degradation of chlorophyll may also occur through the action, in injured green leaves, of chlorophyllase, an enzyme which releases phytol alcohol from the chlorophyll molecule. The presence of chlorophyllase is of practical importance in maintaining the normal green color of many processed food products. Removal of phytol alcohol converts the normally fat-soluble chlorophyll to a water-soluble form which may be extracted and lost in the juices, syrups and cooking water. This results in apparent bleaching of the product.

The actual mode of existence of chlorophyll in plants is uncertain. The chlorophyll preparations characterized chemically are those which have been extracted from living tissues. However, even the most delicate treatment of plant materials may alter the chemistry of complex molecules such as the chlorophylls. It is of interest that degraded chlorophyll end-products may cause pathological conditions, such as photosensitization, when ingested by animals. The fate of chlorophyll after ingestion by animals is not known completely. It has been established that an appreciable portion of the chlorophyll ingested by animals is excreted, apparently unaltered. Although many claims have been made for the nutritive properties of various types of chlorophyll preparations, unequivocal evidence has not been presented to support these claims.

Betaines. The betaines, methylated derivatives of amino acids, are probably widely distributed in plants since the formation of methylamino compounds in plant tissues is very common. However, until recently, methods have not been available for the detection of betaines and this class of compounds has received very little attention. Some of the betaines present in plant tissues are listed in Table 19-52. Trimethyl glycine, the simplest betaine found in nature, is present in relatively large amounts in citrus juices and sugar beet sap. Vast quantities of this betaine are available as a by-product of the refining of sugar from sugar beets. It is extracted, together with the sugar, and remains in the molasses. Sarcosine, the monomethyl derivative of glycine, is found in the edible tubers of *Stachys tubrifera*.

The betaines vary considerably in stability. Trimethyl glycine is very heat stable, while up to 50 per cent of the trigonelline in green coffee beans may be lost during roasting.

In the animal organism, betaine may act as a source of labile methyl groups required in intermediary metabolism. The physiological significance of the betaines in plant tissues is unknown. It has been suggested that methylation is a process of detoxification in both plant and animal

TABLE 19-52. SOME BETAINES FOUND IN PLANTS

Name	Nucleus	Occurrence
Betaine (trimethyl glycine)...	Glycine	Citrus fruit, sugar beet root
Ergothionine	Thiolhistidine	Ergot
Hercynine	Histidine	Mushroom
Hypaphorine	Tryptophan	Seeds of <i>Erythrina hypaphorus</i>
Stachydrine	Proline	Citrus fruit, <i>Stachys tuberifera</i>
Trigonelline	Nicotinic acid	Coffee beans

tissues. It may be significant that betaines occur most abundantly in those plant tissues where the vegetative processes are most active.

Terpenes

Essential oils, resins, sapogenins, carotenoids, gutta and rubber are groups of naturally occurring plant products which are related through their common structural unit, isoprene (C_5H_8). This diverse group of plant constituents may be regarded as being built up of two or more isoprene units which have been modified by ring formation, reduction of double bonds, or oxidation to alcohols, ketones and acids. The lower terpenes, containing up to four isoprene units, make up the bulk of the essential oils. The diterpene derivatives, such as phytol, abietic acid, D-pimaric acid and other resin acids containing four isoprene units, are represented in nature by relatively few compounds. The triterpenes or sapogenins, containing six isoprene units, are found in the free state as well as in the form of glucosides called saponins. The carotenoids, containing eight isoprene units, are solid materials characterized by particular stereochemical arrangements of the component isoprene units and additional double bonds. Gutta and rubber are high polymers of isoprene.

The biogenetic mechanism of terpene formation and the metabolic fate of terpenoid compounds in plant tissues are not known. It has been suggested that terpenes may be intermediates in the biosynthesis of important cyclic carbon nuclei.

Essential Oils. Although the lower terpenes are characteristic of essential oils, other constituents such as mercaptans, normal hydrocarbons, indole and anthranilic acid esters, may be equally responsible for the fragrance of essential oils employed as flavorings or perfumes. Essential oils may be present in all higher plant tissues. However, the oil is generally present in one particular tissue of a plant such as the flowers, fruit or leaves. Over 500 different chemical compounds have been identified in the essential oils of more than 60 families and several thousand species of higher plants. The diverse composition of the essential oils is illustrated in Table 19-53, showing the composition of the volatile oils found in grapefruit juice. Many of the same constituents occur in the peel oils and juice of other citrus

TABLE 19-53. COMPOSITION OF VOLATILE OIL IN A SAMPLE OF FRESH GRAPEFRUIT JUICE

Compound	Amount (%)	Compound	Amount (%)	Compound	Amount (%)
Limonene	75.0	Linalool	0.8	Oxides	1.5
β -Caryophyllene	6.7	3-Hexene-1-ol	.6	α -Pinene	Trace
Caryophyllene	3.8	$C_{15}H_{24}$	.5	$C_{15}H_{28}$	Trace
oxide		α -Caryophyllene	.5	N-Methyl methyl	Trace
$C_{15}H_{22}O$	2.1	Citral	.5	anthranilate	
Linalool monox-	1.8	Carvone	.5	$C_{13}H_{15}N$	Trace
ide		Geraniol	.2	Hydrocarbons, low	Trace
Carveol	1.4	α -Terpineol	.1	boiling	
$C_{12}H_{20}O_2$	1.0	Polyoxygenated	1.9		
$C_{15}H_{26}O$	0.9	compounds		Total	99.8

varieties as well as in essential oils obtained from other plant leaves, fruits and flowers.

Sapogenins and Saponins. The triterpenes or sapogenins, containing 30 carbon atoms, are structurally related to the sterols with which they are often associated in plant waxes. The triterpenes may occur as free sapogenins or bound to glucose as glucosides. In some cases the triterpenes are acids and in other instances they are found as alcohols. Like the essential oils, the triterpenes are generally found in one part of a plant, although in different plants the same triterpene may occur in different tissues as indicated in Table 19-54.

The similarity of alfalfa saponins and the soysapogenols, present in uncooked, solvent-extracted soybean meal, was reported recently. Since alfalfa saponins are known to cause bloat in ruminants, it has been suggested that the soybean saponins may be responsible in part for the growth depressing effect of uncooked soybeans. Toasted soybeans are nontoxic and it has been shown that cooking can hydrolyze saponins to nontoxic sapogenins. The toxic quality of dried alfalfa may be explained by assuming that normal dehydrating conditions are insufficiently drastic to effect hydrolysis of the toxic saponins.

Carotenoids. The tetraterpenoid or carotenoid pigments occur universally in all higher plants and in all tissues including roots, stems, leaves, flowers and fruits. The carotenoids are generally divided into two groups, the hydrocarbons or carotenes and the oxygen-containing xanthophylls. The carotenes are typically soluble in ether, hydrocarbons and halogenated hydrocarbons and practically insoluble in alcohol. The xanthophylls are soluble in alcohol and insoluble in typical hydrocarbon solvents.

The principal carotenes in higher plants are α -carotene, β -carotene, γ -carotene and lycopene. Lycopene is the red pigment in tomatoes and many

TABLE 19-54. SOME TRITERPENES FOUND IN HIGHER PLANT TISSUE

Tissue	Plant	Triterpene	Form
Seed	Soybean	Soysapogenols A, B, C, and D	Saponin
	Shea nut	Bassic acid	Saponin
	Java almond	α -, β -Amyrin	Sapogenin
Root	Sugar beet	Oleanolic acid	Saponin
	Licorice	Glycyrrhetic acid	Saponin
Stem (bark)	Soap bark	Quillaic acid	Saponin
	Guaiac	Oleanolic acid	Saponin
	White birch	Betulin	Sapogenin
Bud	Clove	Oleanolic acid	Sapogenin
Leaf	Alfalfa	$C_{30}H_{50}O_3$	Saponin
	Ivy	Hederagenin	Saponin
	Olive	Oleanolic acid	Sapogenin
Flower	Calendula	Oleanolic acid	Saponin
	Sunflower	Arnidiol	Saponin
Fruit	Cocaine tree	Erythrodiol	Saponin (mono-stearate)
	Apple (skin)	Ursolic acid	Sapogenin
	Cherry (skin)	Ursolic acid	Sapogenin
	Cranberry (skin)	Ursolic acid	Sapogenin
	Grape (skin)	Oleanolic acid	Sapogenin

other red fruits. Lycopene and another carotene, phytofluene, are widely distributed in roots, stems, flowers and fruits, but they are not usually present in leaves. β -Carotene is the most widely distributed of any of the carotenoids and has the highest provitamin A activity. β -Carotene is also the principal carotene in leaves and may occur in quantities of 0.02 to 0.1 per cent. In many plant tissues the brilliant color of β -carotene may be masked by chlorophyll. However, in several mature fruits, such as apricot, peach and squash, β -carotene imparts the characteristic color of the fruit.

α -Carotene is also widely distributed among higher plants although it generally composes a smaller portion of the total carotenes than β -carotene as indicated in Table 19-38.

γ -Carotene is found almost universally, occurring in relatively minute amounts among higher plant tissues. Commercial carotene preparations obtained from palm oil and carrots contain about 0.1 per cent of γ -carotene. It has been reported that γ -carotene may account for as much as 50 per cent of the total carotenoids in the Dutch East Indian fruit *Gonocaryum pyri-forme*.

TABLE 19-55. OCCURRENCE OF SOME PRINCIPAL PLANT CAROTENOIDS

Type	Name	Vitamin A moiety (moles)	Occurrence
Carotene	α -Carotene	1	Carrots, sweet potato, watermelon, chestnuts, red palm oil, soybean oil
	β -Carotene	2	Carrots, Seville orange, tomato, paprika, red palm oil, yellow iris
	γ -Carotene	1	Palm oil, rose hips, pyrocanthea berries, Lily of the Valley (leaves, berries)
	Lycopene	0	Red tomato, watermelon, apricot, rose hips, yellow iris, pot marigold
Xanthophyll	Capsanthin	0	Red pepper, paprika, pimiento, tiger lily anthers (<i>Lilium tigrinum</i>)
	Cryptoxanthin	1	Yellow corn, orange peel, persimmon, papaya, paprika husks, pumpkin flower
	Flavoxanthin	0	Buttercup petals (<i>Ranunculus acris</i>), many green leaves
	Lutein	0	Green leaves, giant winter squash, rose hips, wheat germ oil, marigold flower
	Taraxanthin	0	Dandelion flowers, buttercup petals, rose hips, yellow snapweed
	Violaxanthin	0	Yellow pansy (<i>Viola tricolor</i>), papaya, persimmon, horsechestnut leaves
	Zeaxanthin	0	Yellow corn, tomato, peach, pumpkin, rose hips, Seville orange, pansy flower

The xanthophylls are found in leaves, fruits, flowers and many other tissues of higher plants. Lutein is the major xanthophyll in leaf tissues. The occurrence of some other xanthophylls in higher plants is shown in Table 19-55.

Carotenoids of the green leaf are components of the chloroplasts and appear to be bound in a protein-chlorophyll-carotenoid complex. The weight ratios of the components in the complex are about 80:17:3, respectively, in spinach leaf chloroplasts. Although the carotenoids are not known to perform a specific role in the photosynthetic process, they may function as light filters in leaves and undoubtedly affect the colors of flowers and fruits and hence influence the fertilization of the flower and the distribution of seeds by animals.

Changes in coloration of fruits from green to yellow (e.g., lemons, pears, etc.), orange (e.g., oranges) and red (e.g., tomatoes, strawberries) are associated with either a decrease in chlorophyll, increase in carotenoids or both. Ethylene, produced by many fruits during the climacteric rise in respiration or artificially administered to hasten fruit coloration, causes the destruction

of chlorophyll and the production of carotenoids. Temperature variations strongly affect the carotenoid content of plant tissues. The carotenoids and chlorophyll content of tomato leaves tend to increase with decreasing night temperatures and high daytime temperatures in the range of 4 to 32°F.

Rubber and Gutta. Gutta differs from rubber in that all the double bonds in the former have a trans configuration and contain only about 100 isoprene units, while rubber is characterized by the cis configuration of its double bonds and polymers containing between 500 and 5000 isoprene units. Gutta is a plastic rather than an elastic mass at ordinary temperatures and has a microcrystalline structure. Chicle, which is a mixture of gutta and triterpenols, is used as a base for chewing gum.

Rubber formation is a property shared by widely scattered species of higher plants. Over 2000 species of plants produce rubber in amounts varying between 1 to 20 per cent of the dry weight of the plant. Rubber is found in specialized cells as a microscopic suspension in the serum, forming a milky white fluid called latex. Many non-rubber bearing plants produce latices containing mixtures of proteins, waxes and triterpenol esters. Papaya and fig latices are well-known sources of the proteolytic enzymes papain and ficin, respectively.

The suggestion that rubber may serve as a reserve food in plants may be questioned since rubber once deposited in the plant does not appear to be utilized under conditions of stress. In addition, enzymes capable of hydrolyzing rubber have not been detected in higher plants.

Natural Antibiotics in Plant Tissues

A large number of antibiotic materials have been detected in higher plants. A few of these have been isolated in pure form and characterized chemically as well as in terms of their antibiotic spectre. Although several of the higher plant antibiotics are potentially useful against pathogenic bacteria, molds and viruses, none has as yet shown sufficient promise to warrant therapeutic application.

The bactericidal properties of onion and garlic were demonstrated as early as 1917. The active principle was originally called allicin. However, the name was discarded to avoid confusion with existing pharmaceutical preparation. In garlic, it is found in the form of a thermostable precursor which is liberated enzymatically in crushed cell preparations.

Parasorbic acid (Figure 19-3A), a sweet, aromatic oily liquid isolated by steam distillation from the ripe berries of the Mountain Ash (*Sorbus aucuparia*) is chemically related to sorbic acid, (Figure 19-3B), a white crystalline compound also isolated from a variety of *Sorbus aucuparia*. Synthetic sorbic acid is manufactured commercially and has been used as a fungicide in certain types of food preparations. Sorbic acid has also been used for a number of years to improve the milling characteristics of cold rubber.

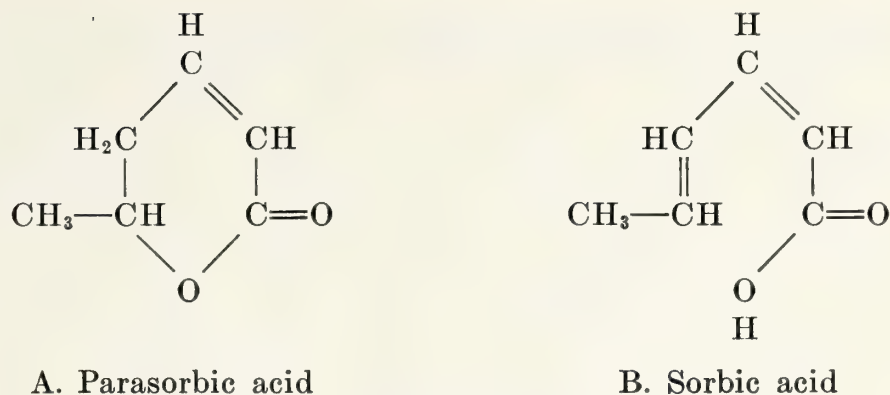


Figure 19-3.

Antibiotic activity has been claimed from various *Cruciferae* including cabbage, turnips, mustard and horseradish. β -Phenethylisothiocyanate, which has been isolated from the roots of several crucifers, including turnips, horseradish and black and white mustards, may be the active principle.

Tomatin, an antibiotic isolated from tomato, has been the subject of extensive investigation. This compound, is present throughout the tomato plant but highest concentrations are found in the leaves. The best source of tomatin is the so-called currant-sized tomato which is a wild, South American variety that produces currant-sized fruit. Tomatin which inhibits gram-positive and gram-negative bacteria as well as certain pathogenic plant and animal fungi, is relatively toxic to animal organisms. Other antibiotics isolated from higher plants include Anemonin from *Anemone pulsatilla*, Crepin from *Crepis taraxacifolia*, and various unnamed compounds with undetermined structures from Common Burdock, Wild Ginger and Goat's Beard. Active principles have also been demonstrated in extracts of cloves, cassia, cinnamon, honey, common ragweed, currants, Clinton grapes, rhubarb, bananas, sweet potatoes, carrot tops, Chinese water chestnuts, blueberries, cranberries, peppers, Hottentot figs, honeysuckle, and Scotch thistle. Antiviral and antibacterial activities have been reported for a number of flavonoid compounds.

Post Harvest Deterioration of Plant Products

The preservation of economic plants and especially those used for food is a problem of extreme and immediate importance to the world population. Recognizing the great contribution which the food processing industries have made in solving many of the problems involved in food preservation, and discounting the significance of insects, bacteria, fungi and pests, much more needs to be done to insure delivery to the consumer of plant products containing their full portion of important nutritional factors.

In general, seeds are among the most stable plant tissues. Legume seeds have been known to retain their viability and germinate after 75 years, while seeds of other plants may be vital for only a few weeks. Other types

of plant tissues may undergo deteriorative changes within a few minutes after removal from the parent plant. It would be of interest and practical importance to know the chemical basis for the rapid deterioration of some tissues in contrast to the great stability of others. It would appear that enzymes are key factors. An active amylase capable of hydrolyzing starch has been found in rye seeds over 100 years old. On the other hand, the relatively rapid changes that occur in potato tubers (Table 19-56) and tobacco leaves (Table 19-57) are also undoubtedly regulated by enzymatic reactions. The application to plant tissues of chemicals: such as maleic hydrazide to inhibit sprouting of potatoes and onions; ethylene to hasten the coloration of citrus; and plant growth regulators to maintain tissue viability may be considered crude, empirically derived, qualitative steps in the direction of controlling enzymatic reactions. It would seem logical to suppose that more detailed knowledge of the chemistry of plants would

TABLE 19-56. CARBOHYDRATE CHANGES IN POTATO TUBERS STORED AT DIFFERENT TEMPERATURES
(Calculated to a moisture-free basis)

Substance	Initial (%)	After storage for 2 weeks	
		0°C (%)	25°C (%)
Starch.....	67.0	61.0	64.0
Glucose-1-phosphate.....	0.0	0.2	0.0
Glucose.....	0.6	0.8	0.6
Glucose-6-phosphate.....	3.5	0.7	4.5
Fructose-6-phosphate.....	0.2	2.5	0.4
Fructose.....	0.2	1.5	0.2
Sucrose.....	1.1	6.7	0.8
Triose phosphate.....	0.4	0.9	0.3

TABLE 19-57. CHEMICAL CHANGES IN EXCISED TOBACCO LEAVES

Constituent	Initial (%)	Time after excision	
		3 days (%)	6 days (%)
Protein, crude.....	1.4	1.1	0.6
Amino acids, free.....	0.07	.23	.22
Asparagine.....	.02	.15	.31
Glutamine.....	.01	.06	.04
Nicotine.....	.104	.097	.087
Sugar.....	.25	.07	.05
Malic acid.....	1.5	.66	.45
Citric acid.....	0.33	.71	.95
Oxalic acid.....	.16	.18	.16

TABLE 19-58. RELATIONSHIP BETWEEN CHEMICAL COMPOSITION-RESPIRATION RATE AND STORAGE LIFE OF VARIOUS EDIBLE PLANT PRODUCTS

Product	A Nonlipide caloric value ^a Btu $\times 10^{-3}$ /ton)	B Lipide, crude (%)	C Respiration rate, °OC (Btu/ton/24 hr)	$\frac{A \times B}{C}$	Approximate storage life (0°C) (days)
Apple.....	408	0.4	770	212	180
Potato.....	570	.1	660	87	120
Orange.....	370	.2	800	92	100
Peach.....	440	.1	1100	40	20
Strawberry....	236	.5	3200	37	10
Tomato.....	145	.3	1020	43	8
Mushroom.....	127	.3	6300	6	2

^a Nonfibrous carbohydrate + organic acids

permit the application of further, perhaps more logical deterioration-inhibiting measures.

An example of how knowledge of the chemistry and physiology of plants might aid in the preservation of plant tissues may be illustrated using the data presented in Table 19-58. It may be seen that for each material, the product of the caloric value (calculated from the carbohydrate and organic acid content) and the lipide content, divided by its corresponding respiration rate, correlates reasonably well with its estimated storage life at 32°F. Certainly the correlation is not perfect. Considerably more data and possibly other factors may have to be taken into account before confidence could be placed in a purely empirical relationship of this kind. This simple relationship may be entirely unjustifiable on the basis of other considerations and only by coincidence apply to the limited number of plant products which have been considered here. However, the conclusions which may be drawn from the data shown in Table 19-58 are consistent with practices now being employed in the handling of plant products. For example, the inverse relationship between respiration rate and storage life is consistent with the use of refrigeration, high carbon dioxide and low oxygen atmospheres to reduce respiration and increase storage life of apples, pears and many other economic plants; as well as with the use of ethylene to increase the respiration rate and hasten the maturation of fruits. The direct proportionality between caloric value and storage life is consistent with the recognized long storage life of many high caloric roots, tubers and oil bearing seeds; and the rapid deterioration of low caloric plant products such as lettuce, asparagus and broccoli.

The quality evaluation of fruits and vegetables, based on visual characteristics such as color, size, texture, etc., assumes that external appearance represents some measure of the composition and hence organoleptic and nutritional value. While this may be true to some extent, there are numerous, obvious examples of the limited usefulness of visual quality analysis.

Fundamental investigations on the chemistry of plants are basic to the development of (a) improved varieties of agricultural commodities, (b) food products having greater nutritional value, (c) better methods for the preservation of edible and other types of plant products and (d) more satisfactory, objective methods for the evaluation of quality in all types of plant products.

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20. POULTRY PRODUCTS

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Poultry Meat and Eggs in the Diet

Foods of animal origin including milk and meats as well as poultry and eggs are recognized to be nutritionally excellent and highly palatable components of the American diet. The per capita consumption of these foods, which come indirectly from crops, is generally high in those areas of the world such as America, where the living standards are high and in areas where adequate feed is available for conversion to animal products⁴⁷. In the case of poultry, feed is converted to meat and eggs approximately as follows: 3 pounds of feed yield 1 pound of meat, while 4 pounds of feed yield 1 pound of eggs. In spite of losses that always accompany the biological conversion of feed to animal products, it is found that poultry is frequently a low-cost source of animal protein and niacin, and eggs are frequently a low-cost source of protein and are occasionally a low-cost source of iron and riboflavin, for the average consumer in the United States¹⁰¹. Since poultry and eggs are nutritionally excellent foods, the increased per capita consumption of these foods since 1935 (Table 20-1) has contributed to the improved nutritional quality of our diet¹¹³.

The increases in per capita consumption of poultry and eggs have undoubtedly involved the following factors: increased efficiency of production and lowered costs relative to other food items; improved quality of products offered to the consumer; availability of improved convenience items such as ready-to-cook birds; and increased general living standard. The 70 per cent increase in egg production since 1930 has been accomplished without appreciable increase in number of laying hens. This increased efficiency of laying has come from the development of genetically better egg-laying strains of chickens and from better management of the birds available. The great rise in poultry meat production has come from the growth of

TABLE 20-1. ANNUAL PRODUCTION AND CONSUMPTION OF POULTRY AND EGGS IN THE UNITED STATES^a

	Average 1935-39	1953
Chickens, farm flocks		
Production, live weight, million lb	2,230	2,310
Consumption, lb (ready-to-cook) per capita . . .	12.1	9.9
Gross income, millions of dollars . . . . .	...	502
Chickens, commercial broilers		
Production, live weight, million lb	200	3,017
Consumption, lb (ready-to-cook) per capita . . .	1.1	13.2
Gross income, millions of dollars . . . . .	...	817
Turkeys		
Production, live weight, million lb	390	959
Consumption, lb (ready-to-cook) per capita . . .	2.1	4.4
Gross income, millions of dollars . . . . .	...	322
Eggs		
Production, farm flocks, number in millions . . .	40,000	61,700
Consumption, number per capita	296	399
Gross income, millions of dollars . . . . .	...	2,440

^a From data reported by the U. S. Agricultural Marketing Service. Values for the per capita consumption of farm chickens and broilers, respectively, are estimates of the authors, and were obtained by dividing the reported per capita consumption of all chickens in the proportion by weight in which farm chickens and broilers were produced.

commercial broiler and turkey operations, which have been economically feasible through improved breeding, feeding, disease control, and processing. Large meat-type birds have been developed with capacities to grow faster and convert feed to meat more efficiently. Coupled with a better knowledge of nutritional growth requirements and establishment of methods of reducing mortality and morbidity in poultry, these developments have permitted production of the bird at less cost per pound. Conversion of the live bird to a high-quality more-acceptable ready-to-cook or precooked product has also been made more efficient through improved centralized slaughtering, evisceration, packaging and marketing methods.

Weights and distribution of weight between parts of the poultry carcass (Table 20-2) vary with species, breed, sex, feed, and age. However, economic considerations and dietary habits have narrowed the list of major commercial classes of product to a few: broiler-fryer chickens of either sex, slaughtered at about 11 weeks of age; stewing hens and cocks, culled from commercial egg and breeding flocks at 1 to 2 years of age; and turkeys in 3 age groups, younger than 14 weeks (fryer-roaster), around 6 months and less than 8 months (young toms and hens), and older than 10 months (toms and hens). It is apparent from Table 20-2 that the percentage yield of marketable or edible weight from live weight increases with increase in the size of the bird.

TABLE 20-2. AVERAGE WEIGHTS AND PERCENTAGE YIELDS FOR POULTRY^a

	Live weight	Dressed weight ^b		Ready-to-cook ^c		Edible meat ^d	
		Net	As % of live weight	Net	As % of live weight	Net	As % of live weight
	lb	lb	%	lb	%	lb	%
Chickens							
Broiler-fryer	3.0	2.6	88.5	1.9	64.0	1.4	48
Roaster	5.0	4.5	89.5	3.4	67.0	2.5	51
Hens	5.5	4.9	89.5	3.7	67.5	3.1	57
Turkeys							
Fryer-roaster	7.0	6.2	88.0	5.0	72.0	3.7	53 est.
Hens, toms, light	11.0	9.8	89.0	8.2	74.5	5.9	54
Hens, toms, medium	18.0	16.2	90.0	13.9	77.0	10.2	57
Hens, toms, heavy	27.0	24.6	91.0	21.2	78.5	16.2	60 est.
Ducks	6.0	5.3	89.0	4.2	69.5	3.2	54
Geese	14.0	12.4	88.5	10.2	72.5	8.0	57

^a Data reported by U. S. Department of Agriculture, Production and Marketing Administration, Poultry Branch, Jan. 1952, except for the last two columns (see *d* below).

^b Dressed poultry has had only the blood and feathers removed.

^c Ready-to-cook poultry has had the blood, feathers, head, and feet removed, and has been fully eviscerated. Ready-to-cook weights include abdominal fat, if any, and neck and giblets.

^d Edible meat consists of ready-to-cook carcass plus giblets and minus the bones. Values were obtained from refs. 8, 60, 61, 69.

Amounts of the major nutrients in poultry and eggs are listed in Table 20-3. The composite mixture of proteins found in the egg has uniquely high biological value⁹⁴, a result of the favorable amounts and proportions of essential amino acids shown in Table 20-4. Poultry meat proteins are also of high nutritional value (Table 20-5), being essentially equivalent to muscle proteins from other livestock. Quality and content of protein from fresh poultry and eggs are practically constant, but contents of vitamins (and some minerals) depend on the amount of the particular nutrient in the hen's diet. For example, the vitamin A content of eggs⁴⁰ may vary from 400 to 1600 International Units per 100 grams due to seasonal variations in available carotenoids from natural feeding stuffs. It is of interest to note that nutrients for which 100-gram portions of whole egg (approximately 2 eggs) contribute more than 10 per cent of the daily human requirement include protein, phosphorus, iron, riboflavin and vitamin A; while 100 grams of poultry meat contribute protein, phosphorus, iron and niacin at greater than 10 per cent of requirements.

TABLE 20-3. NUTRIENTS IN POULTRY MEAT AND EGGS

	Amounts in 100 grams of edible portion of ^a			
	Chicken meat ^b	Whole egg	Egg white	Egg yolk
Calories	150	160	50	360
Proximate analysis				
Water, g.....	71.	74.	88.	49.
Protein, g.....	20.**	13.*	11.*	16.**
Fat, g.....	7.	11.	0.	32.
Ash, g.....	1.1	1.0	0.6	1.7
Carbohydrates, g.....	0.	0.7	0.8	0.7
Minerals				
Phosphorus, mg.....	200.*	210.*	17.	590.**
Calcium, mg.....	14.	54.	6.	140.
Iron, mg.....	1.5*	2.7**	0.2	7.2**
Copper ¹⁰² , mg.....		0.2	0.1	0.4
Vitamins ^c				
Thiamin, mg.....	0.08	0.10	0	0.27
Riboflavin, mg.....	0.16*	0.29*	0.26*	0.35**
Niacin ³³ , mg.....	10.2**	0.07	(0.1)	Trace
Pyridoxin ³³ , mg.....	0.08	0.02		
Pantothenic acid ^{33, 68} , mg.....	0.6	2.0	<0.01	6.0
Folic acid ³³ , mg.....	0.14	0.09		
Biotin ³³ , mg.....	0.008	0.025		
Vitamin A, intern. units.....		1100.**	0	3200.**
Vitamin D ²⁶ , intern. units.....		100.	0	280.
Vitamin E, mg.....		3.0		
Vitamin C, mg.....		0	0	0

* Value represents more than 10% of human daily requirement.
** Value represents more than 20% of human daily requirement.
^a Unless designated by reference number in left column, values were obtained from ref. 112.
^b Data in general obtained from raw tissue of broilers. Values for older birds differ significantly only in greater caloric and fat content and less water, as discussed elsewhere in this chapter. Vitamin determinations are on muscle meat only.
^c Vitamin content of eggs varies directly with vitamin content of the hen's diet, and may differ between diets by as much as several hundred percent. Values, as far as possible, refer to eggs produced on an average commercial poultry diet. Vitamin contents of chicken meat represent mean of values for light and dark meat.

POULTRY

Factors in Production and Processing of Poultry that Affect Quality

The maximum inherent quality of marketed poultry is established long before slaughter not only by the genetic make-up, which limits the potential development of the carcass, but also by the feeding and management

TABLE 20-4. AMINO ACID CONTENT OF CRUDE PROTEIN IN EGGS^a

Amino acid	Per cent amino acid in crude protein ^b			
	White	Yolk	Whole	Shell membrane ⁹³
Arginine.....	5.8	8.2	7.0	6.7
Histidine.....	2.2	1.4	2.4	2.6
Lysine.....	6.5	5.5	7.2	2.8
Tyrosine.....	5.4	5.8	4.3	2.0
Tryptophan.....	1.7	1.7	1.5	2.5
Phenylalanine.....	5.5	5.7	5.9	2.6
Cystine.....	2.6	2.3	2.4	11.2
Methionine.....	4.4	3.0 ⁹³	4.9	5.4
Threonine.....	4.3	3.5 ⁹³	4.9	5.2
Leucine.....			9.2	
Isoleucine.....			8.0	
Valine.....			7.3	
Glycine.....			2.2	

^a Values are those reported by Block²⁷ unless designated otherwise by a numbered reference.

^b Crude protein ($N \times 6.25$) in fractions are 11.9, 16.3, 13.5, and 70% for white, yolk, whole egg, and shell membrane, respectively.

practices needed to fulfill this potential. From slaughtering, throughout processing, storage, and marketing to final consumption, the pertinent problems are those of retaining this inherent quality.

Gross characteristics of the carcass that establish quality include conformation; amount of muscle on the skeletal structure, termed fleshing; the amount of fat in and under the skin, referred to as finish; and freedom from immature pin feathers which are difficult to remove during processing. These characteristics, especially the latter two, are gained gradually as birds mature, so that problems arise whenever immature birds are marketed in order to avoid less efficient feed conversion experienced during later growth. Finish is particularly important in masking the dark flesh surface underneath and thus creating a light pleasing appearance in the final product.

In the dressing operation, which covers slaughter, bleeding and feather removal, the carotid arteries are severed, either from an outside neck cut or through the throat, in order to permit relatively complete bleeding. Inadequate bleeding leaves the superficial capillaries full of blood, resulting in a dark, unacceptable product. Bleeding may be preceded by a momentary electric shock from a high-voltage, low-amperage source of current as a means of reducing struggling and bruising of the carcass. Also inserting a thin knife into the cranial cavity before cutting the arteries, in order to

TABLE 20-5. AMINO ACID CONTENT OF CRUDE PROTEIN IN CHICKEN TISSUES^a

Amino acid	Per cent amino acid in crude protein ^b			
	Light meat	Dark meat	Liver	Gizzard
Leucine	7.0	7.2	8.2	6.0
Isoleucine	5.3	5.7	5.6	4.4
Valine	4.7	4.6	5.6	3.8
Phenylalanine	3.8	4.0	4.6	3.2
Methionine	2.1	2.8	4.1	2.6
Tryptophan	1.2	0.9	0.7	0.8
Threonine	3.9	3.8	5.1	4.5
Histidine	3.7	2.9	3.8	2.5
Arginine	5.9	6.1	7.1	5.6
Lysine	7.5	8.8	7.3	6.0
Tyrosine ²³	4.2	4.3		
Cystine ²³	1.3	1.3		
Serine ²³	4.7	5.4		
Glutamic acid ²⁸	(16.5) ^c			
Glycine ²⁸	(<1)			
Alanine ²⁸	(2)			
Aspartic acid ²⁸	(3.2)			

^a Values are those reported by Millares and Fellers⁹¹ unless designated otherwise by numbered reference.

^b Crude protein (N × 6.25) in tissues are 23.3, 18.4, 18.9, and 19.8% for light meat, dark meat, liver, and gizzard, respectively.

^c Values in parentheses are for samples described only as chicken meat.

loosen the feathers, is still practiced to some extent, principally with turkeys.

Feather removal is quite generally accomplished commercially by scalding, which consists of immersion (or spraying) of the bled bird in water of specified temperature for a specified time, followed by exposure of the bird to the action of rubber feather-picking fingers mounted on power-driven rotating drums. Temperature of the scalding water is critical, while duration of scalding is of secondary importance with respect to the ease and completeness of feather removal, and also with respect to the subsequent appearance and storage characteristics of the product.

Scalding at 125 to 130°F for 45 to 60 seconds, termed semiscalding or slack scalding, has been used predominantly throughout the development of commercial mechanized poultry processing. Water in this temperature range loosens the feathers to a considerable degree but leaves the outer epidermal layer of skin relatively unchanged. Scalding at or around 140°F for about 30 seconds, known as subscalding, has been adopted in some cases in place of lower temperatures because it produces a clean, completely pin-

feather-free, ready-to-cook product at reduced processing cost. Subscalding, in contrast to semiscalding, loosens the outer epidermal layer which is subsequently removed by the automatic rubber fingered pickers, resulting in a skin surface much more susceptible to dehydration and darkening during processing, storage, and marketing. Consequently subscalded birds must be protected from moisture loss, first by chilling in slush ice or cold water rather than air, and subsequently by packaging and keeping in moisture-proof material until the birds are cooked. Scalding at 180 to 190°F, termed hard scalding, is more hazardous to quality than subscalding and, since it offers little more advantage in feather removal, there is practically no commercial use of the 180 to 190°F range.

Evisceration of poultry in large centralized processing plants immediately or shortly after dressing has increased from a minor percentage in 1930 to at least 30 per cent of total production in 1952. Advantages of marketing eviscerated or, as it is preferably called, ready-to-cook poultry are the elimination of the inconvenience, inefficiency, and esthetic undesirability of eviscerating birds in the retail market or home, the reduction in weight for freezing or shipping, and removal of the hazard of development of visceral taint by diffusion of substances out of the intestinal tract into the meat. The ready-to-cook product must be treated with great care to avoid moisture loss, rancidification of the fat, and bacterial spoilage in the visceral cavity. Ready-to-cook birds are marketed to an appreciable extent as cut-up poultry, which further increases the exposed surface area of the product.

Processed poultry is marketed in two principal forms or states—chilled and frozen. A preponderant majority of commercially processed chicken broilers and fryers are sold in the chilled state, while a major portion of the turkey production is marketed as a frozen product. The major quality problem in chilled poultry is bacterial spoilage; shelf life under average commercial conditions is limited to 5 to 10 days. Hazards in the storage and marketing of frozen poultry concern dehydration with adverse changes in appearance and the development of rancidity in the carcass fat. Since 1950, increasing demands for quality convenience items have led to a rapid rise in the production of precooked frozen poultry products. Production figures are not available. However, the products include chicken and turkey pies, a la king, loaves, rolls, croquettes, turnovers, chicken chow mein, fried chicken, barbecued chicken, sliced turkey and chicken fricassee. Special problems that have arisen in the freezing of these products concern the maintenance of flavor, tenderness, and juiciness during freezing, frozen storage, and reheating. Another convenience item, canned poultry, represents somewhat less than 5 per cent of total production as estimated from volumes certified for canning. A small amount of smoked turkey is produced.

Constituents of Poultry Meat Important to Quality

Water in chicken meat, which is shown in Table 20-3 as 71 per cent for broilers, actually varies inversely with the fat content⁸⁹ and thus may range from 71 per cent for broilers to 56 per cent for very fat hens, the respective fat contents in these two cases being 7 and 25 per cent. On a fat-free basis the water, protein and ash content of poultry flesh is essentially constant. Changes in water content of poultry tissue following slaughter is important from at least two standpoints. Since the product is almost always sold by weight, loss of water by evaporation during processing, chilling, freezing, or frozen storage represents a direct economic loss. And, loss of water results in appearance changes that reduce consumer acceptability. A shrinkage in air chilling usually amounting to 1 to 2 per cent can be prevented by chilling in slush ice or cold water. In fact, slush ice chilling as practiced commercially results in a net weight gain of 2 to 3 per cent. Dehydration in frozen birds first occurs around the feather follicles, with the appearance of small white rings, and if allowed to continue to a 1 to 2 per cent loss in carcass weight, the objectionable chalky whiteness spreads until it is quite general over the skin surface. This dehydration is prevented commercially by packaging eviscerated carcasses in reasonably moisture impermeable material.

The fat content of poultry tissue varies widely not only with respect to type of tissue but also with respect to age, sex and estrogenic treatment, and nutrition. Tissue in the breast muscle of broilers may contain as little as 0.3 per cent fat, while abdominal fatty tissue in a hen may have as much as 80 per cent. Fat or lipids may be divided roughly into two types: simple triglycerides or neutral fat which overwhelmingly predominate in the fat depots under the skin and in the body cavities; and compound lipids, such as the phospholipids, which make up an appreciable portion of the crude lipids in certain vital organs such as the heart and liver. Since the phospholipids appear to have a specific function in the metabolism of the bird, they have a characteristic fatty acid composition, containing appreciable percentages of the more highly unsaturated (tetraenoic, pentaenoic and hexaenoic) fatty acids⁹⁹. In contrast, neutral fat which serves as a source of reserve energy has a fatty acid composition that reflects to a considerable degree the composition of the dietary fat. The fatty acid composition of neutral, depot fat in a particular bird does not vary significantly between different locations in the carcass⁶⁵. That is, fat in the skin layer is quite similar to fat in the visceral cavity, a condition quite contrary to that found in other livestock such as the hog. Typical values for the fatty acids in poultry depot fat are presented in Table 20-6.

Stability of poultry fat is intermediate in the realm of food fats, being less stable than beef fat or coconut oil but more stable than moderately unsaturated vegetable oils, such as soybean oil. Relative stability is con-

TABLE 20-6. FATTY ACID COMPOSITION OF BODY FATS FROM HENS

Fatty acid	Percentage distribution of fatty acids in abdominal, gizzard, and neck depots of birds ⁶⁵	
	7 months old	2 years old
Myristic.....	0.1	1.0
Palmitic.....	25.9	24.5
Stearic.....	6.7	4.2
Hexadecenoic.....	7.0	6.9
Oleic.....	38.1	42.6
Linoleic.....	21.8	19.8
C ₂₀₋₂₂ unsaturated.....	0.4	1.0

TABLE 20-7. CHARACTERISTICS OF POULTRY FAT AS RELATED TO SPECIES AND DIET

Species and diet ^a	Characteristics of fat in visceral cavity								
	Iodine no.	Toco-pherols	Induc-tion period	Fatty acid content (%)					
				Satu-rated	Mono-ene	Diene	Triene	Tetraene	Pentaene
		<i>μg/g</i>	<i>hr</i>						
Turkey									
(a) Experimental diet A contain-ing beef fat (iodine no. of 57).....	63	—	55	30	61	4	0.3	0.1	—
(b) Diet A contain-ing soybean oil (iodine no. of 121).....	72	—	15	32	49	13	1.1	0.3	—
(c) Commercial diet B.....	80	10	12	33	40	19	2.4	0.1	0.5
(d) Diet B plus 0.1% tocoph-erol.....	80	90	65	33	40	19	2.3	0.1	0.5
Chicken									
(c') Diet B.....	79	25	40	34	40	19	2.3	0.2	0.2
(d') Diet B plus 0.1% tocoph-erol.....	81	400	120	34	38	21	2.4	0.2	0.2

^a Runs (a) and (b) represent one experiment⁷⁷; runs (c), (d), (c'), and (d') repre-sent another experiment (90).

ditioned primarily by two factors as indicated in Table 20-7: fatty acid composition and tocopherol content. The first two rows of data in Table 20-7 show the marked change in fatty acid composition and decrease in stability (induction period) caused by replacement of 2 per cent of beef fat

by 2 per cent of soybean oil in an experimental low-fat diet. Data in the last four rows demonstrate that the fatty acid composition of turkeys and chickens fed the same diet is essentially the same, and that the inherently greater stability of chicken fat compared to turkey fat is due to the greater level of tocopherol deposition effected by the chicken.

It is clear that the stability of poultry fat, which involves prevention of oxidative rancidity, can be increased considerably with dietary supplements of the naturally occurring antioxidants, tocopherols. Stabilization of the highly susceptible fat in the surface layers of frozen eviscerated poultry can also be accomplished by the application of synthetic antioxidants of acceptable food grade⁷⁹. Rancidity in frozen, whole, eviscerated poultry stored for as long as 12 months is, however, not a serious problem provided the bird is packaged in essentially impermeable film and held at 0°F or below. Danger of rancidification is greatly increased when poultry is cut up before freezing and storage, because of the increased surface exposed to atmospheric oxygen⁷⁶. Rancidification is also a problem in the storage of precooked frozen poultry, but it can be controlled in many cases by use of antioxidants⁸².

Objectionable off-flavors in cooked poultry fat, characterized as fishiness, have been traced to the presence of excessive amounts of fish oil in the diet, particularly in the period just prior to slaughter¹⁵. Usual recommendations for avoidance of this hazard are to reduce fish oil content of diets to 1 per cent or less and eliminate fish oil from the finishing diet (last 6 weeks). Typically fishy flavors and odors can also be produced in cooked turkeys by the presence in the diet of a highly unsaturated vegetable oil, linseed oil⁷⁸.

Proteins of poultry tissue have not been isolated and studied in detail, but they are so similar to the proteins of other animal tissues that have been investigated that their general nature can be inferred with some assurance. Muscle²⁰ is made up principally of extracellular protein (collagen and elastin) and intracellular protein, which includes actinomyosin, globulin X, myogen and myoglobin. In addition, crude muscle contains a great number of soluble minor constituents, such as carnosine, anserine, creatine, adenosine triphosphate, urea, ammonia, glutathione, amino acids, and mineral elements. Actinomyosin is the contractile element of muscle and represents over half of the total proteins present. The elastin and collagen content increases with the age of the bird and imparts a toughness to the cooked meat. Collagen, or the gelatin to which it is converted on cooking, has a lower biological value than the intracellular protein, due to its relative deficiency in several of the essential amino acids.

Poultry muscle differs from other animal proteins such as beef in that it does not require a prolonged aging period for the development of maximum

tenderness. However, if birds are cooked immediately after slaughter, before the onset and resolution of rigor have taken place, the meat is very tough, stringy and rubbery even in young birds⁵⁹. Holding the slaughtered bird at refrigerator temperatures for 1 to 2 days is usually long enough to permit complete resolution of rigor and maximum tenderness in the cooked meat.¹⁰⁸

Minor constituents of poultry, which include the skin and muscle pigments, flavor precursors, vitamins, minerals, and enzymes, are important in establishing appearance, flavor, nutritive value, and stability. However, their chemical nature and reactions are not in all cases completely understood. Pigments are readily deposited in the skin of birds that do not have genetically white skin. The pigments are principally xanthophylls derived from the diet, and hence the degree of pigmentation is roughly proportional to the level of pigment in the feed. Some commercial broiler feeds are fortified with crude xanthophyll concentrates because of consumer preference for a yellowish carcass. The laying hen mobilizes visible deposits of xanthophylls in the shanks, feet, beak and other surface appendages and incorporates them in the egg, and thus the degree of bleaching of the shanks, etc., can be used as a convenient index of egg production. We have already mentioned the undesirable effect of inadequate bleeding with resultant retention of the red respiratory pigment hemoglobin in the superficial tissues. In frozen and thawed broilers, hemoglobin in the bone marrow has a tendency to diffuse out of the immature bone and cause a "dark bone" condition in the cooked bird. This condition does not develop in older birds which have a hard bone structure and a decreased hematopoietic function. Myoglobin, a compound somewhat similar to hemoglobin, is present in the muscular tissue of the leg and thigh and contributes to its darker color.

The nature of the components of chicken tissue that are essential to the formation of flavor in the cooked product, and the chemical characteristics of the flavor constituents themselves, are not well understood. On a weight basis, the most potent source of flavor is the muscle and the least is the fat, the skin and bones being intermediate⁹⁷. Some factors contributing to the flavor of chicken broth can be extracted from the raw meat with cold water. This water-soluble fraction includes a considerable proportion of mineral salts, which contribute to the over-all flavor. Flavor components in chicken broth have been fractionated²⁹ by distillation and distribution between solvents to yield three crude fractions containing "meaty" or chicken broth odor characteristics.

Vitamins and minerals (Table 20-3), which make a valuable contribution to the nutritive value of poultry, have otherwise few known effects on quality or stability. Carotenoids, some of which have vitamin A activity, are sources of the pleasing yellow color of chicken fat, and also probably

serve as antioxidants since they become bleached just prior to complete rancidification. The most potent antioxidant in the tissue fat is, of course, another vitamin group, the tocopherols, which have been discussed above in connection with the fats.

Microbial Contaminants of Processed Poultry

Bacterial contaminants in poultry are obviously not true constituents but their presence makes it necessary to consider them as important negative components of the commercial product. Sources of contamination include the environment of the live bird, the scalding tank and other processing equipment, the viscera, and the hands of processing plant personnel. The greatest bacterial hazard exists in the marketing of chilled but unfrozen ready-to-cook poultry, in which bacterial spoilage may render the product unacceptable after one week of storage at usual commercial holding temperatures. Prevalent types¹⁶ of bacteria on processed poultry include the following genera: *Pseudomonas*, *Micrococcus*, *Achromobacter*, *Flavobacterium*, *Acaligenes*, *Proteus*, *Bacillus*, *Sarcina*, *Streptococcus*, *Eberthella*, *Salmonella*, *Escherichia*, and *Aerobacter*. Chromogenic bacteria represent 50 to 60 per cent of the initial bacterial contamination on processed poultry, but these are displaced during chilled storage by a preferential growth of *Pseudomonas* and to some extent gram-negative cocci. Approximately 10⁸ microorganisms per square centimeter of skin are ordinarily present before off-odor or slime becomes evident¹⁶. Bacterial spoilage can be controlled or minimized by sound sanitary practices in processing and packaging, by storing chilled poultry at temperatures near 32°F and by the use of chlorinated water (10 to 20 ppm) in processing and chilling of ready-to-cook poultry⁴³.

EGGS

Table 20-8 breaks down the utilization of eggs into fairly large categories. It is readily estimated from Tables 20-1 and 20-8 that the value of commercially broken out eggs is well over one hundred million dollars even though they represent only 5.7 per cent of the eggs available (a minimum figure). Naturally a great many products are made from commercially broken out eggs.

Bakeries, mayonnaise and salad dressing manufacturers, and noodle manufacturers use frozen eggs primarily in their products. Confectioners use egg white solids primarily and the dry prepared mix industry of course uses egg solids exclusively, in their products. Although the amount of egg solids now used is small compared with frozen egg, increasing amounts of egg solids are being used by industry because of their improved quality.

Bakers use broken out eggs to make cakes, sweet rolls, cookies, dough-

TABLE 20-8. UTILIZATION OF HEN EGGS IN THE UNITED STATES IN 1953^a

	Number of eggs in millions	Per cent of domestic supply
Eggs available.....	68,124	100 ^b
Eaten on farms.....	6,557	9.6
Used from backyard flocks.....	6,168	9.1
Set on farm.....	121	0.2
Eggs sold (total).....	55,278	81
Commercial hatcheries.....	2,736	4.0
Broken out eggs.....	3,852	5.7
Frozen.....	3,216	4.7
Egg solids (dried eggs).....	444	0.7
Other.....	192	0.3
Shell eggs sold for table and commercial use in shell form.....	48,690	71

^a Private communication from P. B. Dwoskin, Agricultural Marketing Service, U. S. Department of Agriculture. Excess of exports over imports amounted to 389 million eggs, or 0.6% of total supply. Net use of eggs from inventory was equivalent to 640 million shell eggs.

^b Includes eggs that are a complete loss (possibly 5% of eggs available).

nuts, pies, pastries, bread, sweet dough and other products. The prepared mix industry uses egg solids in cake, doughnut, cookie, soup, ice cream, breading and other mixes.

Inedible eggs are used for a variety of purposes including special types of leather tanning, crown seal adhesives, pharmaceuticals, lithography, and animal feed¹¹.

Constituents of Eggs in Relation to Egg Preservation and Use

The edible portion of the egg contains some sixteen substances that are at a sufficiently high concentration to have an important influence on one or more of the properties or uses of the egg. Representative or average values for the occurrence of these substances in egg white and yolk are given in Tables 20-9 through 20-12. Approximately 95 per cent of whole egg solids is protein and lipide and these components generally determine the properties of egg products. However, major components are not always the controlling factors. For example, the free glucose content, which amounts to only 1.1 per cent of the egg solids, leads to serious deteriorative reactions when present in the dry products (Table 20-13). It is now common to eliminate glucose from eggs prior to drying either by fermentation or by enzymatic oxidation of the glucose to gluconic acid, which is relatively inert^{18, 32, 48, 72, 73, 103, 109}.

The values in Tables 20-9, 20-10, 20-11, and 20-12 are based on but are not necessarily simple averages of values reported in the literature^{3, 4, 10, 11, 12, 13}. The proteins listed in Table 20-10 are not in all cases

TABLE 20-9. AVERAGE COMPOSITION OF EGG WHITE, EGG YOLK, AND WHOLE EGG (57 Gram Egg)^a

	White	Yolk	Whole egg
Average weight per egg (grams)	33	18	51 ^b
Dry weight per egg (grams)	4.3	9.2	13.5
Water (%)	87	49	73.5
Solids (%)	13	51	26.5

Composition of Egg Solids (%)

Protein (lipide free)	92	32	51
Lipides	1.5	63	43
Free sugar (95% glucose)	3.0	0.4	1.1
Other nitrogen-free organics	(0.5)	2.4	1.8
Inorganic	3.0	2.2	2.4
Sulfur	1.5	0.35	0.7
Phosphorus	0.13	1.16	0.8
Nitrogen	14.2		

^a Compiled from various sources including refs. 3, 4, 10, 11, 12, 13.
^b Shell and membrane weigh approximately 6 grams¹².

TABLE 20-10. EGG WHITE PROTEINS (92% OF SOLIDS)^a

	Amount (%)	Molecular weight	Isoelectric point	Properties	
				Special	Functional
Ovalbumin	63	45,000	4.8	—	Foams on whipping. Heat coagulates in mer- ingues, cakes, etc.
Ovomucoid	11	28,000	4.3	Inhibits trypsin	Essentially inert
Conalbumin	12	87,000	6.0	Binds iron	Essentially inert
Lysozyme	3.7	14,800	11	Lyses certain bacteria	Increase rate of foam formation
Globulins, G ₂ and G ₃	8	—	6	—	
Ovomucin	1.9	—		Virus antihemag- glutinating ac- tivity	Influences foam sta- bility and viscos- ity of egg white
Avidin	0.05	66,000		Binds biotin	—

^a Compiled from various sources including refs. 3, 13, 86.

completely homogeneous. Thus, ovalbumin contains two major and one minor component (cf. 13). They differ apparently in their phosphate content—A₁, containing the most phosphorus, can be converted to A₂ and A₂ to A₃, which is free from phosphorus⁹⁶. Ovomucoid has been separated electrophoretically into three major and two minor components, all of which

TABLE 20-11. EGG YOLK CONSTITUENTS (REPRESENTATIVE VALUES)^a

	Per cent of yolk solids	Per cent of lipide-free proteins	N (%)	P (%)	Properties
Lipovitellin.....	17	—	13.0	1.5	} Probably related to development of rubberiness on freezing
Vitellin.....	14	45	15.7	1.0	
Lipovitellenin...	12	—	10.0	1.6	
Vitellenin.....	8	25	15.5	0.3	
Phosvitin.....	2.2	7	11.9	9.7	
Livetins.....	7	22	15.5	0.5	
Neutral fat.....	39				
Lecithin.....	15				} Emulsifying
Cephalin.....	6				
Cholesterol.....	3				
Total.....	94 ^b	99			

^a Compiled from various sources including refs. 3, 11, 13.
^b Total does not include the lipoproteins, since these contain lipide; also the vitellins may contain some phosvitin. For remainder see Table 20-9.

TABLE 20-12. FATTY ACID COMPOSITION OF EGG LIPIDES^a

Fatty acid	Percentage distribution of fatty acids in lipide fractions ¹⁰⁰		
	Lecithin	Neutral fat	Total lipide ^b
Myristic.....		0.7	0.5
Palmitic.....	32	25	27
Stearic.....	4	7.5	6
Palmitoleic.....		3	2
Oleic.....	43	52	49
Linoleic.....	8	9	9
Clupanodonic.....	13	2	6
Total saturated.....	36	33	34
Total unsaturated.....	64	67	66

^a Shorland (*New Zeland J. Sci. Technol.*, **B33**, 224 (1951)) reports certain differences in lipide composition values from these.
^b Calculated from columns 1 and 2 on assumption that cephalin has same fatty acid composition as lecithin and that the phospholipids are one-third of the total lipide.

possess trypsin inhibitor activity²⁵. Enzymes except for lysozyme occur in only very small amounts in unincubated eggs⁸³.

The composition of eggs may vary as a result of diet, breed, environment, and other factors. The percentage of yolk tends to decrease with decreasing egg weights below 50 grams^{11, 12}. Marked differences in the amounts of some of the proteins present have been reported; e.g., values for conalbumin have ranged from 9 to 16.8 per cent of the egg white proteins, and for ovalbumin from 60 to 70 per cent¹³. While some variations

may be due to the method of analysis, there is little doubt that considerable variations in composition do occur. The influence of feed on the composition of apparently normal eggs is most notable in the fatty acid composition^{14, 38, 39} and color¹⁰⁶ of the yolk. Reports that the protein composition of thick and thin white differs have not been substantiated^{44, 51, 84} except for ovomucin, which is concentrated in thick white^{19, 88}. The latter contains 4 to 9 times as much crude mucin as thin white. The percentages of mucin in thick and thin white change with storage time, but the total amount of mucin apparently does not change¹⁹.

The physical and chemical properties of the egg proteins have been reviewed in great detail recently^{3, 13}. Lysozyme has attracted special interest because of its alkaline isoelectric point, its ease of crystallization and large crystal size, and its lytic activity¹. In the following discussion, generally only those protein and lipid properties that appear to be closely related to the preservation and utilization of eggs will be of interest.

Shell Eggs. The nonmicrobial deterioration of shell eggs evidently involves very subtle chemical changes. Flavor changes originating within the egg have not been identified chemically. Lowering the temperature and storage in CO₂^{36, 104} retard the changes in flavor. The increases in NH₃,

TABLE 20-13. REACTIONS THAT OCCUR IN EGGS AND EGG PRODUCTS^a

Reaction	Products involved	Principal results
1. Glucose-amine (a) Glucose-protein	Dry egg white, yolk, and whole egg	Decrease of solubility and functional properties, browning, increased fluorescence.
(b) Glucose-cephalin	Dry whole egg and yolk	Browning of phospholipid, increased lipid fluorescence, off-flavors.
2. Oxidation	Dry whole egg and yolk	Off-flavors, loss of carotenoids, formation of lipid oxidation products
3. Loss of CO ₂	Shell egg	pH increase, change in mucin (?) and loss of thick white
4. Miscellaneous reactions (rates very slow)	Shell egg	Increase in NH ₃ , free fatty acids, Fe and PO ₄ transfer from yolk to white (importance to flavor unknown), loss of lysozyme
5. Denaturation (?) of lipoproteins	Frozen whole egg and yolk	Viscosity increase, gelation.
6. Mucin-lysozyme complexing	Shell egg	Loss of thick white
7. Iron and H ₂ S to give FeS	Shell egg, scrambled egg if alkaline.	Green color due to black FeS and yellow yolk

^a Compiled from various sources (see text).

free fatty acids, free phosphate, and transfer of Fe and PO_4 between yolk and white that occur on extended egg storage have not been proved to be involved in flavor changes¹⁰⁴.

Nonflavor changes accompanying deterioration are more readily measured than the flavor changes. The loss of CO_2 , increase in pH, decrease in amount or quality of thick white, change in yolk index, and loss of moisture are readily measured on the broken-out egg. The decrease in thick-white quality as measured by the white index is considered an important physical quality factor^{11, 62}. Change in this quality factor involves ovomucin. The mucin is a very viscous protein, which occurs as fibres apparently enmeshing liquid to form the thick white^{36, 52, 86, 105}. Isolated mucin disperses under alkaline conditions such as develop in egg white on loss of CO_2 . Whether the alkalinity factor alone is responsible for egg white thinning is not known. The possibility that mucin-lysozyme interaction is responsible has been suggested recently in a study of complex formation between mucin and lysozyme⁶⁴. Complex formation between lysozyme and other less basic proteins tends to occur because of the high isoelectric point (pH 11) of lysozyme. In this connection it should be noted that lysozyme activity of eggs decreases on storage⁴⁴, and that the difference in lysozyme content of eggs laid by the same hen appears to be negligible, whereas definite differences between hens exist¹¹⁴.

The proteolysis theory of egg white thinning is no longer held¹⁹. Unequivocal elucidation of the mechanism of thinning remains a challenging problem.

Egg White Solids (Dried Egg White). Commercial egg white solids, ordinarily prepared from white freed of glucose, are quite stable. If glucose were present in the dried product, the whites would become dark colored, the proteins would become insoluble, and consequently the whipping properties would be lost^{21, 31, 75}. The functional properties of the white (foaming properties particularly) are markedly influenced by processing conditions. Here again, mucin appears to be an important protein. When egg white is subjected to high shear forces the whip time increases. The mucin isolated from egg white submitted to high shear forces has a different physical appearance from that of ordinary egg white^{24, 50, 87, 107}. It is not known whether other proteins are also altered. It is said to be necessary to remove mucin prior to drying to retain good whipping properties. But removal does not necessarily assure a good whipping product, especially of spray-dried egg white. Furthermore, it has not been definitely established that removal of mucin is necessary for the retention of whipping properties under all processing conditions. The properties of reconstituted spray-dried white are different from fresh white. The specific proteins or reactions responsible for this difference have not been identified.

Contamination of white with egg yolk (whether dried or not) markedly

interferes with foaming¹⁷. As might be expected, a number of substances influence the foaming properties of egg white, e.g., oils, milk fat, salt, sugar, etc.¹¹.

Frozen Egg White. Freezing raw egg white apparently does not alter the proteins in any important way^{34, 104}. High shear forces in handling the egg white will, of course, alter the mucin and the whipping properties as already indicated. Freezing cooked egg white has an adverse effect on its texture⁴¹.

Whole Egg and Yolk Solids (Dried Whole Egg and Yolk). The properties of whole egg are much more like the properties of yolk than white and these dried products may therefore be discussed together. Products containing yolk solids will deteriorate rapidly at room temperature and above unless glucose is eliminated^{58, 71, 74}. Glucose reacts not only with the proteins but with the phospholipid cephalin⁷⁰. The latter reaction leads to off-flavors while the former presumably is largely responsible for the decrease in functional properties that accompanies storage²¹. Both lead to darkening of the egg.

Although oxygen does not appear to be involved in shell egg deterioration, it does cause off-flavor development in whole egg and yolk solids. Furthermore, the products of oxidation differ in egg solids dried with and without sucrose (20 to 30 per cent solids basis)³⁷. The precise reasons for this difference have not been established. Presumably it is connected with the condition of the fat in sugared and unsugared egg. Thus, cold petroleum ether will extract 100 per cent of the lipid from plain whole egg solids while it will extract only 7 per cent from the solids containing sugar³⁰. Histological examination reveals extensive coalescence of the lipid from the plain egg, while in the sugared egg the lipid is in a diffuse state comparable to its condition in liquid egg⁹⁸. It is possibly of related interest that small-sized particles of milk fat have less detrimental effect on egg white foaming than large particles⁴².

Whole egg and yolk lose their sponge-cake-leavening power on drying, whether by spray drying or lyophilization. However, these products retain their leavening power if 10 per cent sucrose is added to the egg before drying. Two lines of evidence implicate the lipids. First, the lipid constituents are in a different state of distribution in the powders, as already indicated, and second, the whipping (and leavening) properties are recovered if the egg solids are extracted with cold ether or acetone⁶⁷. Apparently the extraction removes a foam inhibitor or surface-active agent, possibly released by drying in the absence of sucrose. Drying influences the properties of lipovitellin⁸⁰ and sucrose reduces the effect⁶³.

The components of yolk responsible for the leavening power have not been identified.

Frozen Whole Egg and Yolk. Freezing and thawing of whole egg and

yolk lead to a great increase in viscosity and even to a tough or rubbery consistency, particularly in the yolk. This change has been associated with the lipoproteins of yolk^{80, 92, 110}. Lipovitellenin prepared from frozen egg yolk is less soluble and possesses less lipid than lipovitellenin from unfrozen yolk⁴⁶. The effect of freezing on lipovitellin has been described in some detail⁸⁰.

The development of rubberiness is minimized in yolk by the addition of sugar or salt, generally 10 per cent. The mechanism by which these additives influence the lipoproteins and gelation has not been established, though knowledge of the protective action of sugars on proteins is not new. Homogenization or milling prior to freezing also minimizes the effect on the yolk¹¹⁰. Except for the difficulty of handling, which may be severe in the case of yolk, the functional properties of yolk and whole egg are altered to only a small extent by the rubberiness⁶⁶.

Constituents of Egg Shell and Membrane

The characteristics of the shell and shell membrane of eggs influence the moisture and CO₂ loss from the egg, its breaking strength, and probably its resistance to microbial invasion. Therefore, egg shell has received considerable attention by research workers¹¹. Recent results have shown that not only shell thickness but also pore count, porosity coefficient, and the amounts of membrane protein, shell protein, pore protein, matrix protein, and citric acid indicate the individuality of the bird¹¹¹. Differences between eggs of different birds are much greater than differences between eggs of a single hen. On the other hand, the calcium, magnesium and carbonate content of the shell does not differ significantly between birds¹¹¹.

The shell has the following average percentage composition: calcium 38, magnesium 0.6, carbonate (CO₃) 55, protein 1.5, remainder (trace minerals, water, etc.) 5¹¹¹. The shell membrane, 4 to 5 per cent of the shell and membrane, is 20 per cent protein, 70 per cent water and 10 per cent inorganic matter¹¹. The uses for egg shell and membrane are limited because they are primarily calcium carbonate (approximately 90 per cent).

Microbial Contaminants of Eggs and Egg Products

The importance of the economic losses due to microbial contamination of eggs and egg products is well recognized. Factors influencing the contaminations will be mentioned briefly.

Egg yolk is an excellent medium for growing microorganisms, but egg white is somewhat inhibitory to some bacteria and actually destroys other bacteria by virtue of its lysozyme content. Fortunately, the interior (and the shell) of newly laid eggs are usually sterile¹¹. The shell, of course, becomes contaminated in the nest. Whether the interior becomes contaminated depends on the soundness of the shell and membrane, the humidity,

temperature, the manner of washing (if washed), and the nature and extent of contamination^{35, 45, 49, 53, 54, 57, 85}.

Liquid, frozen, and dried eggs are, of course, contaminated with bacteria. If the eggs are improperly handled the bacteria may cause readily detected decomposition⁸¹. The relative importance of various sources of contamination varies with the type of egg and the breaking and handling procedures⁵⁶. The presence of pathogenic microorganisms, especially *Salmonella*, and spoilage microorganisms in both frozen^{22, 116} and dry egg products⁹ has led to the instigation of pasteurization of yolk and whole egg^{55, 95, 115}. The marked tendency of egg to coagulate or thicken at pasteurizing temperatures (above 140°F) makes it necessary to use low differentials between the heating plate temperature and the desired egg temperature. Since a severe heat treatment is required to destroy large numbers of bacteria, it is especially important to prevent excessive contamination⁹⁵.

Standards and Grades for Poultry and Eggs

Standards have been established by the United States Government with respect to types, classes, styles, grades, weight ranges and permissible methods of processing and marketing poultry, and grades, weight ranges, and operating standards for shell eggs, frozen eggs, and dried eggs. Since these standards are subject to occasional revision, the latest information should be obtained by inquiry of the Marketing Services Division, Agricultural Marketing Service, U. S. Department of Agriculture, Washington 25, D. C., or the Chicago Quartermaster Purchasing Office, 1819 West Pershing Road, Chicago 9, Illinois.

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21. FOOD ENGINEERING

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Introduction

Increasing urbanization of our population and the resultant time lag between the point of food production or processing and the consumer's table impose serious problems with respect to the quality, nutritional value and cost of foods. In a simpler economy in which the consumer was close to production, quality measured the success of the grower and the skill of the local handler with whom food processing was an art. Modern conditions call for much greater skill in maintaining acceptable flavor, color and consistency in both raw and processed foods. The scientist and engineer have come to the aid of the food manufacturer in developing controllable standardized procedures. These assure the maintenance of quality and greater convenience in use in the foods which reach our pantry shelf.

The function of the food chemist is to ascertain general principles of chemical and biological changes which affect the flavor, odor, color, composition and nutritive value of foods between the point of production and that of ultimate use. His importance to the food industry is well emphasized in today's popular slogan "From seed to plate, it's chemistry all the way." However, knowledge of chemical change cannot, of itself, assure success in processing foods. Such information must be translated into terms of plant design and operating procedures which enable the manufacturer to attain the goals which he sets up for his products. This situation has created a need for a person versed in the principles of engineering who would serve as liaison man between the food chemist and the food processor. Such a food engineer utilizes knowledge developed by the chemist to so design and construct the plant, design or select suitable equipment, lay out and operate the process that the manufacturer will be assured of predictable controlled performance and costs under specific conditions.

If the food processor relies on haphazard guessing as to costs of product

development, construction, and operation, as well as of marketing, he invites disaster. Competent food engineering can remove the guesswork. Its objective is the conservation or preservation of foods and the production of new food combinations to provide the best possible acceptability, quality, convenience, and nutritive value at a minimum cost to the consumer. The food engineer must be sufficiently experienced in industrial production, processing, handling and distribution of foods as to be able to apply pertinent scientific knowledge in an effective and efficient manner. He must depend not alone on chemistry for assistance but must draw on such other fields as physiology, biology, physics, mathematics and economics. This type of information is essential when business and technical decisions involving substantial sums of money must be made by the food manufacturer.

Food engineering in many respects involves unit processes and unit operations similar to those of chemical engineering. But, in addition, it deals with effects on the acceptability of a food product which appeals to the consumer on the basis of cost, attractive appearance, organoleptic desirability and convenience of preparation. These considerations are of such importance as to preclude the rigidity in classifications which is possible in chemical engineering.

The past decade has witnessed rapid development in the technological approach to food processing problems. In the present status of food research laboratories the functions of food technology as well as food engineering are often carried out by the same group or individual. Today there is a growing tendency to utilize the food engineer to handle questions which involve unit operations, leaving to the food technologist the field of unit processes. At present a food engineer is usually skilled as well in food technology. However, one can draw a distinction between engineering and technology in many branches of the food industry. The extraction of oil from soybeans is a unit operation (separating) which may be carried out either by mechanical expelling or with suitable solvent. The chemical transformation of the extracted oil into a hardened fat through catalytic hydrogenation is a unit process. In the production of maple sugar from sap, the farmer carries out several unit operations including collecting, heat exchanging and evaporating. Subsequently, he induces a change of phase through crystallization which might be viewed either as an operation or as a process. In reducing the sap to a sirup, a characteristic color and flavor is developed through chemical transformation which would classify this as a unit process. These examples are illustrative of the distinction which is now being drawn in the food industry between unit processes and unit operations.

One of the early exponents of the value of considering the similarities of operational steps performed in many diverse branches of the food industry

was Dr. L. V. Burton. He called attention in 1940 to the fact that the "unit operations in food engineering group themselves naturally into 15 different classifications." These were listed as: cleaning, coating, controlling, decorating, disintegrating, drying, evaporating, forming, heat exchanging, materials handling, mixing, packaging, pumping, separating, and storing. The numerous subdivisions possible under each of these major headings have been noted by many authors, 23 or more having been listed under the single unit operation of separating. In general, Burton's breakdown has been accepted by the technical men in the industry. However, storing is preferably grouped with materials handling, while weighing or measuring is so important in the food industry that many would treat it separately instead of considering it under the operation of controlling. Use of ionizing radiation is developing with such rapidity as to give promise in a few years of warranting its being listed as a new unit operation in the food industry.

A notable trend in food processing in the United States today is toward operating in as continuous and automatic a system as can be realized. Such push-button processes reduce the number and extent of manual operations, assure a more sanitary product, and make possible instrumentation which can deliver a more uniform and controlled foodstuff. For the design, construction, equipping and maintenance of such a stream-lined factory a competent and experienced food engineer is a prime requisite. However, where labor costs are low or the large amounts of capital required for automatization are not available the batch system can be made an effective method of operation.

Materials Handling

Materials handling is concerned with the movement and storage of materials. It is probably the most widely applied unit operation in the food industry, being resorted to repeatedly all the way from the farm to the point of final delivery to the ultimate consumer. It involves harvesting of crops, transportation of the raw unprocessed foodstuffs to an assembly point, receiving of such in the plant, conveying of them into and through the processing lines which includes elevating of solids and pumping of liquids, together with stacking, shipping and warehousing of the packed product until final delivery to the retail food store. The proper integration of plant operations with the deliveries of raw food materials requires an exact timing in harvesting to prevent either gluts or slackness in processing sequences. Since most fresh unprocessed foodstuffs are highly perishable and their rate of maturing is controlled by the cultural factors of rain, sunshine, time and temperature, which are only calculable as statistical averages, the difficulties in realizing this objective are patent.

In recent years much progress has been made through experimentation

in varietal selection and crop husbandry to provide greater flexibility in the processing of food products in the plant. Methods for determining the desired point of maturity in the ripening of vegetables such as peas and corn have aided greatly in insuring fine eating quality in processed fresh vegetables. Increasing application is being made at the point of production of such operations as field cleaning, protective packaging, and snow-icing of market vegetables, to insure high quality on the consumer's table.

In contrast to vegetables, fruits are harvested at various stages of maturity. Bananas and pears are picked green and subsequently ripened to the desired point under controlled storage conditions. Pineapples must be cut at the stage when they just reach ripeness. Peaches are picked when they are still on the firm side and not quite ripe. Exact timing of harvest is less critical with fruits than with vegetables.

When handling animal products, which can be assembled in large quantities at a central point, the application of refrigeration becomes practical and makes spoilage or deterioration prior to processing more controllable. Market milk is cooled at the farm immediately after drawing from the udder and is protected against temperature rise during transport to the factory. In deep sea fishing, the catch is iced in the hold to retard spoilage before return of the trawler to port, which may involve an interval of as much as two weeks. Experimental trawlers have been built with mechanical refrigeration installed aboard, whereby the fish may be frozen in the round and carried in this state until the shore factory is reached, or filleted, packaged and quick-frozen at sea. Animal carcasses are cooled rapidly after slaughter and carried at low temperatures if to be sold as fresh meat.

Problems of materials handling for transport vary with the food product. Live-stock such as sheep or cattle may be driven in herds to rail loading stations, or directly to abattoirs. Poultry and swine are handled by truck direct from the farm. For gathering fruit, the orchardist uses lug boxes or truck trailers in which the fruit may be transported to the packing point. Various types of baskets and hampers serve for small fruits, nuts, and vegetables. Milk is transported in 40-quart cans or by insulated tank trucks. Grain is carried in sacks or in trucks with box bodies to the elevators for loading into cars.

Upon arrival at the processing plant, many raw materials are handled manually, often with the aid of pallets and fork-lift trucks. Grain is unloaded into the mill from freight cars or steamships by suction pipes or by bucket conveyors. In some installations freight cars are tilted over depressed hoppers. Milk is hand-dumped, weighed and pumped to storage vats. Fish are scooped or forked into nets which are hoisted out of a trawler and emptied onto a belt-conveyor. Live stock is driven to the slaughtering floor, stunned manually or electrically, or gassed with carbon dioxide, killed and strung up by one leg to a mechanical overhead trolley.



(Courtesy Counsel Machine Co., Inc.)

Figure 21-1. Model A-1070 Robo-Lift bucket elevating conveyor elevating cut macaroni from extrusion press to overhead belt feeding drum spreader of continuous dryer.

One function of the food engineer is to move food materials mechanically in large quantities in any direction at a minimum cost. For solid materials, he must select that type of conveyor, whether it be screw, bucket, flight, belt, or some other, which meets the particular requirements of the job. For liquids, he will be concerned with piping, pumping, and collecting, selecting those metals which will be resistant to solution in the liquid and inert in their effect on the quality of the food being handled.

In the transfer of raw materials in containers and the finished goods in cases, the food engineer works out a program which fits equipment and manpower to the flow of product. He takes into account initial cost and annual upkeep of equipment, studies physical limitations of space, floor loading, elevator capacity and door dimensions, and prescribes permissible temperature and humidity conditions for warehousing.

Cleaning

While cleaning might be treated as a form of separating, it is usually considered as an operation by itself. It involves the removal of dirt, grease

and varying foreign material from foods prior to processing. Not only is there a legal necessity to remove extraneous foreign materials and residues which may be left by pesticides applied to the growing crops but cleaning prevents spoilage and improves the eye appeal of the food. Such foreign substances as iron fragments are taken out of dried products like tea or grains by magnetic separators. Slotted discs are used to clean round seeds from wheat, while scourers remove foreign material lodged in the creases of the kernels of grain. Sticks and stones found in raw rice are taken out by a scalper, the beards and stems with a clipper, while a monitor serves to aspirate blighted grains.

The cheapest and most universally effective cleaning agent is water. It is likewise the most important solvent in the food industry. Not only must water be clean, fresh and palatable if it is to be used in food processing, but it must be suitable from the bacteriological standpoint. Chlorination is widely employed to render plant water supplies safe. High mineral contents are objectionable in process water because of possible damage to equipment and injury to the manufactured product, particularly its flavor. Ion exchange treatment is used in the beer industry and elsewhere to remove such minerals. These may interfere with the fermentation of the grain. Plant tissues such as peas and beans may be damaged by hardening in the presence of large amounts of dissolved calcium and magnesium. In contrast, in processing apples or tomatoes such dissolved salts are an advantage. Undesirable odors or flavors may be removed from process water by sand filtration, which is a form of gravity filter often used in conjunction with flocculating agents. Filtration through carbon granules is used for some beverages before bottling.

Water is used to clean raw fruits and vegetables by soaking or agitating in tanks or through the use of high-pressure sprays directed onto the food material as it moves through a rotating screen or reel or over a slotted belt. Berries are washed on a pulsating belt which minimizes bruising of the fruit. For removing sand and dirt from spinach, floor washing is employed. In many mills wheat is scrubbed under a flowing stream of water, the bulk of which is subsequently removed by a type of centrifuge called a "whizzer." Hot water, usually with the addition of chemical detergents, is employed to clean re-used containers such as milk bottles, milk cans and beverage bottles. Air cleaning is applied for cleaning seeds and grains.

For many food processing purposes, it is necessary to have air which has been treated to remove entrained dust, oil particles, and other foreign material. This can be done with the aid of filters, water sprays or ultra-violet irradiation. Still another type of cleaning occurs in filtration of liquids such as milk, which may be accomplished by forcing the liquid through a milk cloth in a two-part chamber, or alternatively by passing it

through a clarifier, which is a high-speed centrifugal machine similar in principle to the milk separator but with only one delivery nozzle.

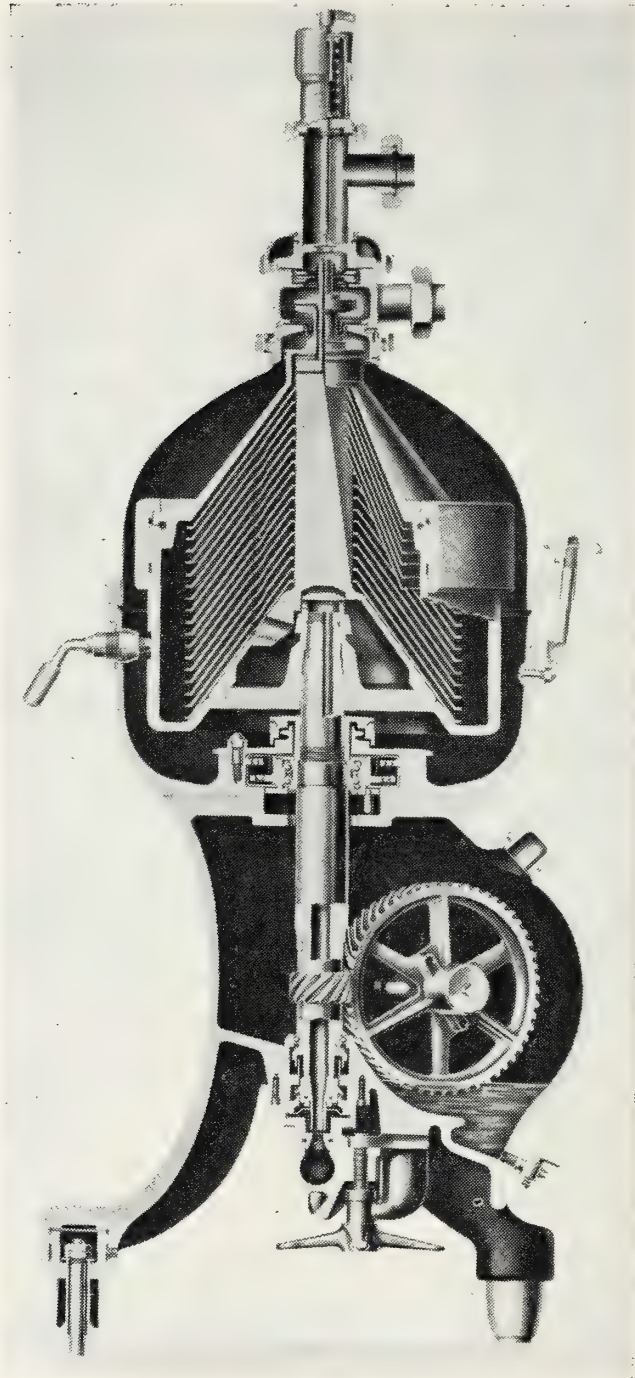
Separating

Separating as a unit operation is accomplished in many ways. Depending upon the material under treatment it may involve air classifying, centrifuging, coring, draining, dressing, evacuating, expressing, filtering, some aspects of grading, peeling, percolating, pitting, pressing, rendering, screening, sifting, skinning, sorting, trimming, and other methods of lesser importance. Governmental regulations may prescribe certain grade standards to be applied, as for ripe tomatoes, live stock, eggs, or milk products. In commercial practice grading by size is applied to many raw foods such as oranges, peas, and cranberries. Since separation by grade affects the price paid for the raw material, its careful control is important. Sorting is carried on repeatedly throughout the entire processing of foods, for separating out defective material and segregating units by size, color, or variety. Trimming serves to remove damaged portions of fruits, vegetables, meats and other raw foods, and is of particular importance because of the biological significance of rots, molds, and bruises.

Peeling is carried out in many ways. Prevailing high wages make hand-peeling extremely rare today in the United States. Mechanical equipment has been developed for many such applications as in paring skins from apples. Abrasive rolls are employed for removing the outer layer from carrots and potatoes. Heat is utilized for giving a quick surface cook in the peeling of tomatoes, beets and peaches so that the skin slips easily from the body of the fruit or vegetable. Chemical agents are widely employed for peeling of peaches and apricots and for hulling of hominy. Such terms as shelling, husking and vining are self-explanatory as to their special application to particular foodstuffs.

Pitting is done by revolving rolls which separate seeds from such fruits as cherries, raisins, prunes, currants and apricots, while coring is employed in the processing of apples and pineapples. Coffee and vanilla extracts are obtained from ground beans by percolation with a suitable liquid, the operation being also classifiable as solvent extraction. Fruit juices are separated by pressing grapes, oranges, apples and other fruit. Cream is obtained by centrifugation of the fat portion from the serum portion of milk at a high speed in continuous equipment designed to calculated dimensions and velocities derived from mathematical relationships.

The dressing of animals involves a sequence of separating operations. After slaughter, the carcasses are hung up to permit thorough draining of the blood, following which they are sorted, skinned or defeathered and trimmed. Swine are dehaired by scalding, abrasion and singeing. Subse-



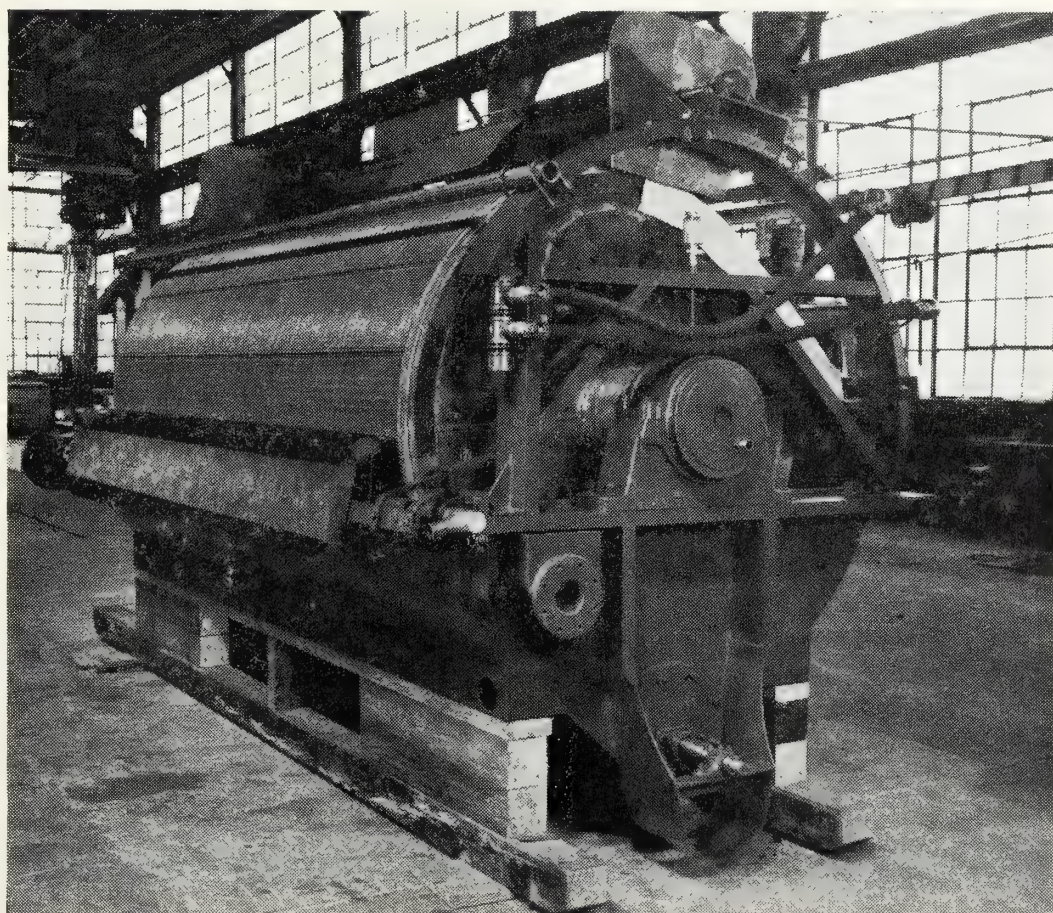
(Courtesy The DeLaval Separator Co.)

Figure 21-2. Cutaway view of #292 DeLaval "Air-Tight" separator.

quent evisceration is followed by Government inspection before dissection or cutting into parts for further processing or marketing. All such dressing operations must be carried on rapidly and continuously to minimize biological changes which may lead to off-flavors and spoilage. The leaf fat and fatty animal tissues are separated from the meat and rendered by application of heat. This operation may be carried out dry in a kettle by means of direct heating, or the fat may be wet-rendered in an autoclave with steam under pressure. Open kettle rendering brings about chemical changes which give rise to a characteristic flavor and odor in the fat. In contrast, the retorted product is bland in flavor and almost water-white.

Further types of separation of fluid components from solid constituents are gravity separation, filtration, expressing and solid extraction, which some writers treat as separate unit operations. Filtration may be carried out by gravity, pressure, vacuum, or centrifugal force to separate the liquid or juice from solid particles of food. The jelly bag which was to be found in every pantry years ago is a filter dependent on gravity for its effectiveness, as is the dairyman's milk strainer. In commercial service the plate and frame filter-press is widely used. It is customary to add some filter aid to the liquid material before filtration to build up a porous bed on the filter-cloth. This bed improves the removal of solids with a more uniform rate of flow. Filters dependent on negative pressure are suction types which may be either continuous or discontinuous. The laboratory Gooch or Buchner funnels, in which a bed is first built up with paper pulp, asbestos or other fibers, are illustrative. The rotating suction filter operates continuously with no operating labor. The withdrawing of the filtrate, formation of cake, aerating, washing (when required) and discharge of cake, go on simultaneously as the drum rotates to present a succession of compartments to each stage of operation.

Cottonseed oil is commonly separated by expressing the liquid from the seed. Preparation of the seeds involves delinting and decorticating fol-



(Courtesy Oliver United Filters, Inc.)

Figure 21-3. Oliver continuous vacuum filter as used in starch plants.

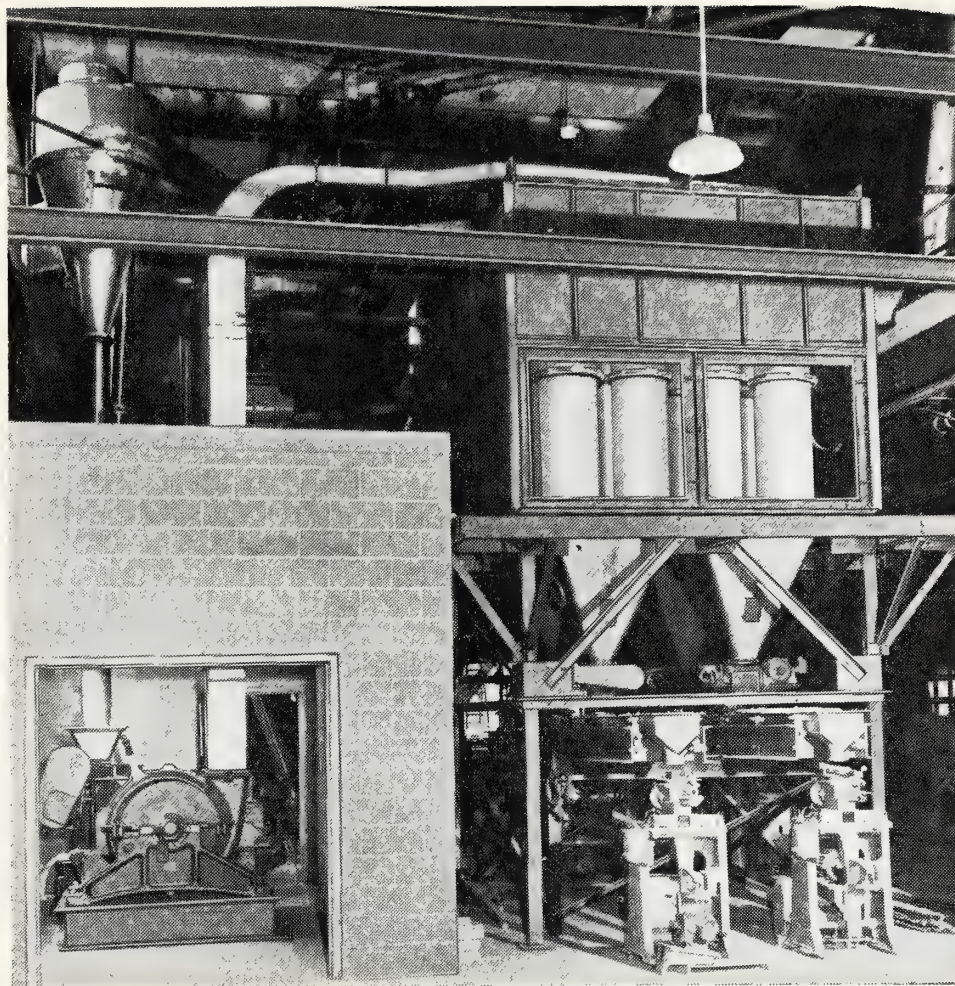
lowed by aspiration to remove the hulls. The seeds are then flaked by rolls and steam-cooked before loading into hair cloth sacks. The oil is pressed out with hydraulic force under pressures of about 2000 psi. For dry seeds, such as soybeans, Anderson expellers based on the turning of a worm in a slotted curb, usually tapered toward the discharge end, are commonly employed. These are particularly suitable for small oil mills where investment in solvent extraction equipment is not justified by the volume of material handled.

Solvent extraction is a form of separating, though it is sometimes classed as an operation by itself. It is frequently combined with pressing for separating out oil from soybeans or cottonseed. It produces a cake of very low residual oil content. Several types of integrated equipment for extracting oil-bearing seeds are in common use. Soybeans require flaking prior to charging into the extractor. Flammability of the solvent presents a definite hazard in this operation, particularly since it is essential, in the interest of economy, that the bulk of the solvent be removed for re-use. Solvent extraction finds another application in the decaffeination of coffee with trichlorethylene, a nonflammable solvent.

Disintegrating

The operation of disintegrating includes many methods such as breaking, chipping, chopping, cutting, dicing, grinding, homogenizing, milling, pulping, slicing and spraying. The one objective of each application is to reduce the particle size of the food material. Friction is used to accomplish this purpose in attrition mills, roller mills, Foos (studded plates) and Buhr (corrugated stone) mills. Refining in the chocolate industry involves roller-milling, melangeuring and use of conching rolls to achieve the extreme smoothness necessary. Meat cutting in the packing plant provides portions suitable for curing, pickling, or smoking. Fresh meat is marketed under refrigeration in halves or quarter-carasses and is cut locally by the retail butcher. The trend today in the meat department of supermarkets is to pre-cut and wrap in plastic sheets individual slices, chops and roasts. Breaking may be accomplished by a sustained pressure or by a sharp blow. Tomato juice is extracted by a "hot break" followed by passage of the liquid through a pulper and finisher to remove skins, seeds, and tough meat portions. Oranges may be crushed to extract the juice as in the Skinner rotary press but are more regularly cut in halves and reamed in Food Machinery Co. Super Juicers. This serves to extract the juice with a minimum of peel oil content. The Bireley Citromat accomplishes much the same objective in another way. Centrifugation is frequently resorted to for removing excess orange oil down to a maximum of 0.03 per cent.

Sugar cane yields its juice through a series of crushing, shredding and



(Courtesy Pulverizing Machinery Co.)

Figure 21-4. Mikro-Atomizer with Mikro-Collector.

pressing operations. Pulping provides a means for utilizing damaged fruit which cannot be packed whole. The resultant puree of formless mass finds many outlets in the bakery, confectionery and ice cream trades, and at the same time, supplies raw materials for fruit jam.

Homogenization is a form of disintegration dependent on shearing action. Suspensions of solid particles or fat globules are fed through a narrow passage under pressure. Colloid mills of either the gravity or pump-feed type operate on this principle. Application of high frequency sonic force to effect homogenization holds promise of increasingly wider adoption. More familiar are the valve-type or the single-service cone homogenizers. Frequently two valves or stages are used in tandem with high pressure on the first stage and low pressure on the second. Disintegration of the fat in heated ice cream mixes is accomplished by homogenization under 2500-lb gauge pressure but results in a viscous product when chilled. The fluidity desired for air incorporation during freezing of the mix can be obtained if a second stage is employed whereby the viscosity is lowered through use of pressures of 500 to 1000 psi.

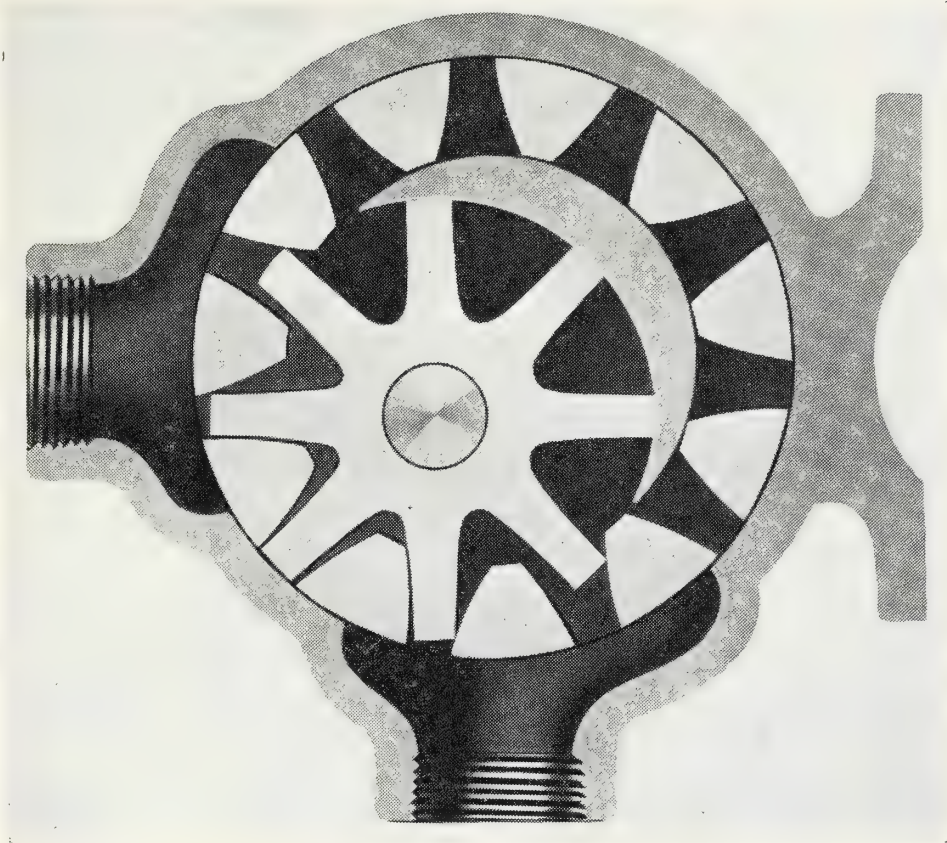
A spray-dryer represents another application of the operation of disinte-

grating. Among its manifold adaptations to food products may be mentioned the drying of whole and skim milk and of whole egg and egg yolk. A number of fruit juices are successfully spray-dried with the addition of a carrier or drying aid. Soluble coffee from "unfilled" concentrated extracts is one of the fast growing spray-dried foodstuffs. The breakup of the liquid to small particles from which the liquid can be quickly evaporated may be accomplished by pumping under high pressure through a small orifice, or by feeding onto a rapidly revolving disc, or by feeding into bowl atomizers. With pressure sprays the size of the droplets and, consequently, of the dried particle is controlled in part by the size of the spray orifice and in part by the tangential motion imparted to the spray by the design of the nozzle. Centrifugal speed, concentration of solids and nature of the feed material are important factors in the control of droplet size with disc or bowl atomizers. The subject of spraying for the purposes of drying food products would require a complete volume to cover adequately the design and operation of the various types of units and spraying devices.

Pumping

Pumping operations constitute a form of materials handling which is employed to move fluids or gases and, sometimes, soft solids, but is so widely used as to warrant treatment as a distinct unit operation. Gravity flow may be utilized where the fluid material is located at a higher level, as by siphoning a liquid out of a tank to a lower level receiver, or purification of water in a sand bed. Liquids also may be moved by steam ejectors or by air lifts.

Pumps are classified either as positive displacement or centrifugal, and are rated on the basis of their capacity, the increase in pressure or head, power applied, and efficiency. For light liquids a reciprocating type of pump is commonly used; such equipment also handles heavy sirups and fuel oils. These pumps deliver a constant volume against a wide range of head pressures. In operation it is necessary to have a by-pass or relief valve on positive displacement pumps. Their efficiency is measured by the work done on the fluid divided by the electrical energy to the pump or by the work done on the pump. Rotary pumps, such as Westco and Waukesha, are a positive displacement type which give more uniform flow but require very small clearances between the housing and the meshed rotating gears. They are especially suitable for high viscosity liquids. These rotary pumps are simple in construction, small in size, relatively inexpensive and have a high discharge pressure. No large solids can be present in liquids which are moved by rotary pump because of the small clearances; however, fine slurries can be handled satisfactorily. The suction line must be large in diameter and short in length, and perfect pipe fitting is an absolute essen-



(Courtesy Viking Pump Co.)

Figure 21-5. Viking rotary pump principle.

tial. A small air leak on the suction side will decrease pump capacity and cause it to be noisy. In the Viking pump there is an idler gear and a rotor which successively mesh, disengage and mesh again during each revolution of the pump shaft. Liquid is sucked in one port and forced out the other located 270° around the casing. Rotary pumps can operate against a maximum suction lift of 25 feet. Their efficiency is above 80 per cent when operating between 400 and 1000 psi pressure.

The Moyno is an unique positive displacement pump of the rotary type. It consists of a single-thread helical rotor turning in a double-threaded helical stator. It is self-priming and liquid flow is uniform. It will pass particles in suspension of a size equal to one-half of the clearance space or the opening between the stator and rotor. No portion of the casing is used as a sealing surface. The mechanical efficiency is relatively high.

Centrifugal pumps are particularly useful in handling milk or cream since they are extremely sanitary and easily disassembled for cleaning purposes. Such pumps are low in efficiency and develop a high turbulence effect. The liquid is moved by a high speed impeller rotating in a volute casing. A valve for throttling the flow, which is continuous, must be installed on the delivery side of centrifugal pumps. A maximum suction lift of 15 ft is generally accepted as a safe operating condition.

The selection of the type and size of pump needed for a particular mate-

rials handling operation requires a knowledge of conditions under which it is to operate, coupled with good engineering calculations. The capacity of a positive displacement piston pump can be calculated from the following equation:

$$\text{gpm} = \frac{A \times L \times N \times E}{231 \times 100},$$

where

- A = piston area in sq in.,
- L = piston stroke in in.,
- N = number of discharge strokes per min
- E = volumetric efficiency in percentage (about 95), and
- 231 = volume of 1 gal in cu in.

The capacity of centrifugal pumps is usually estimated on the basis of a discharge velocity of 10 ft/sec. Then their rating can be calculated from the following formula:

$$\text{gpm} = \frac{10 \times 60 \times 12 \times \pi}{231} \times R^2$$

$$\text{or } \text{gpm} = 98 R^2$$

where

R = radius of the discharge pipe in in.

$$V = \sqrt{2GH}$$

where

- V = velocity of flow, ft/sec
- G = 32.2 ft/sec,² and
- H = total head in ft

A very interesting application to a food material of pumping and fluidizing operations is a recent installation for moving flour from hopper cars to storage bins. A telescoping pipe, fitted with a retracting "snorkel-like" tip, runs from the car top port to a separating cyclone located at the top of a tower. About a 7-lb suction is developed by a Fuller pump to pull the flour to the cyclone. A similar pump acts as a "pusher," jetting air in through holes and sweeping to the tip through an outer concentric tube. Unloading speed is about 15,000 lb of flour per hour, the material dropping from the cyclone into storage silos.

Mixing

The unit operations discussed previously have dealt with the handling and preparation of raw food materials for processing. In the conversion of

these into finished products mixing is applied under widely varying operating conditions. This may serve one of several useful purposes. Mixing may be used to produce a satisfactory blended product of two or more miscible fluids such as molasses and water, or two or more uniformly divided solids such as sugar and milk powder. Mixing may bring about physical changes as by solution of a gas such as chlorine in water. Similarly, the deodorization of vegetable oil may be effected by blowing super-heated steam through it. The decolorization of sirup by means of vegetable carbon is due to the physical change of adsorption. Another use of mixing is for the purposes of dispersion, e.g., finely divided solids in a fluid, as in the manufacture of mayonnaise or salad dressing. Homogenization of an ice cream mix results in a dispersion that will not separate or segregate. Another objective of mixing may be the promotion of a reaction, as in the hydrogenation of vegetable oils. Whipping air into ice cream mix during freezing utilizes gas under pressure in a continuous freezer or under atmospheric conditions in batch equipment. Packing of whole milk powder in an inert gas atmosphere exemplifies mixing of a gas with a solid material. The carbonation of beverages such as beer and soft drinks involves the mixing of a gas under pressure with a liquid.

The blending of liquids is generally carried out in cylindrical tanks furnished with propeller or impeller agitators. The former may be mounted on the top, side, or bottom of the tank, which may have a flat, dished-out, or shallow cone bottom. The depth of liquid is maintained at from 1 to 2 times the tank diameter. Impellers may be turbine, flat-paddle or marine type in shape, and not over one-third the tank diameter in cross-section. Frequently baffles are mounted on the tank walls to change the flow pattern of the liquid. The length, location, and angle of the baffles affect this pattern. The configuration of the tank, the location of the impeller and the characteristics of the liquids blended are factors determining the flow pattern. In any instance, vortexes should be avoided if good mixing is to be expected.

The development of mixing methods for particular liquids should be carried on in commercial equipment, if at all possible. If the pilot plant is to produce information necessary for translating to full commercial operation, the mixers must have sufficient flexibility for the determination of the factors that will affect the ultimate choice of the type of mixing equipment. Certain empirical methods of scaling up agitator designs for constant performance have been developed for selected agitation functions. If the experimental results are to be applied effectively the laboratory mixers should be of such design as to be easily copied on a larger scale.

Agitation for mixing liquids can be performed in various ways. Two streams of liquid can be mixed by passage together through a centrifugal pump. Air agitation is utilized in the sterilization of liquid food in tins. A

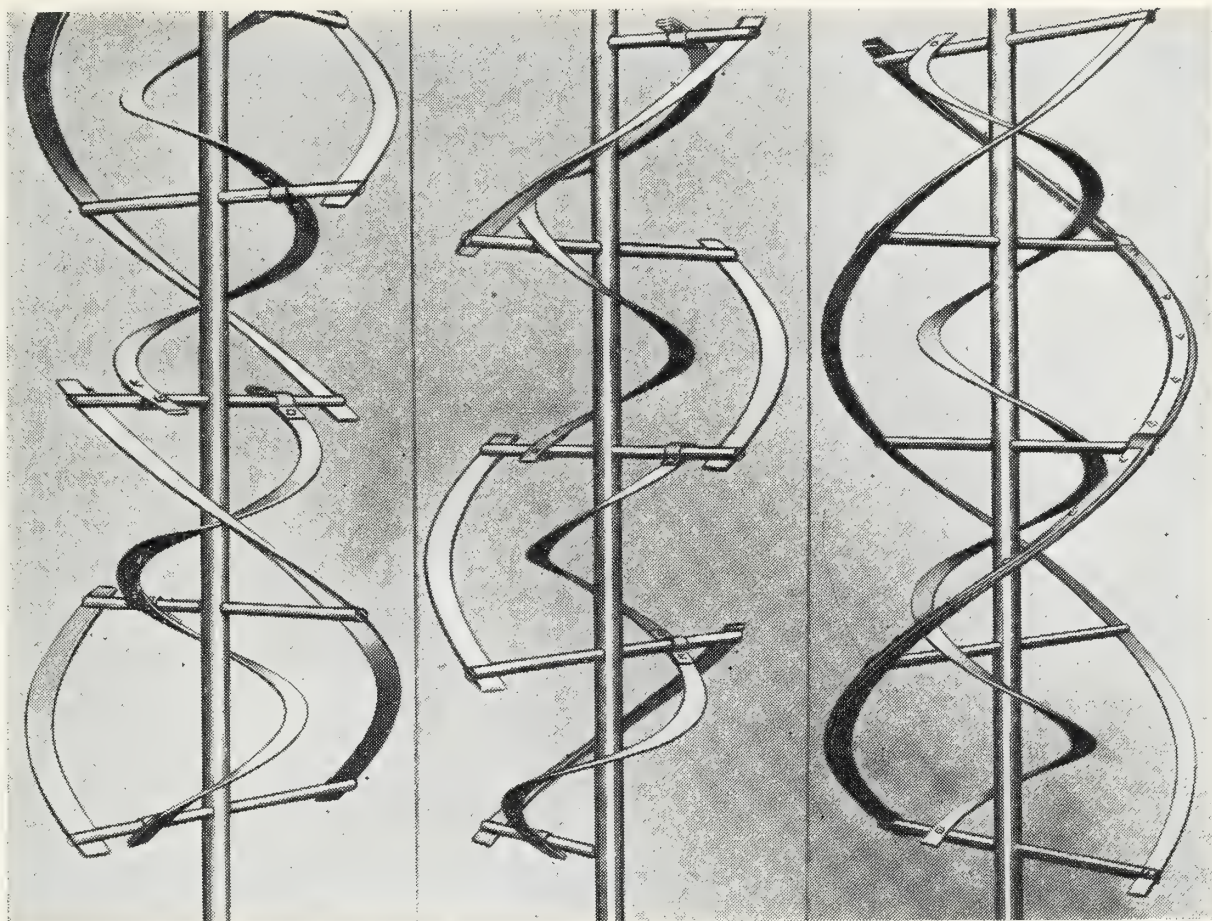
head space of $\frac{1}{4}$ to $\frac{3}{8}$ in. is left in the can when it is closed. Movement of the can causes this air to move through the liquids, which is productive of rapid heat penetration. End-over-end rotation is most effective, and the increase in heat exchange thus brought about promotes flavor preservation.

Paddle type, or arm mixers, are probably the oldest method of agitation. These rotate axially, causing the material to be actually pushed or carried around in a circular path. The greatest short-coming of the paddle type is that it produces no effective motion perpendicular to the blade, such as would cause different strata to mix together. The installation of baffles can overcome such stratification to a considerable extent. Paddle mixers offer the advantage of low cost and are entirely satisfactory for many kinds of work. They have the advantage that they do not incorporate air. For mixing solids with liquids, the paddle or arm type mixer is used in a number of applications. In the dough mixer fitted with sigma blades, the rotating arms effect transportation, kneading, tearing, stretching, and folding. Usually such kneaders are made to empty by tilting. The planetary type of paddle mixer is widely used for paste and doughs, and in the manufacture of such products as cake batter and mayonnaise.

Colloid mills are used where extremely fine dispersions of a solid in a liquid are required. In principle, the materials are fed between a very rapidly revolving solid rotor and its casing, with clearances as fine as 0.001 in. The combination of intense shear and centrifugal force acts to make excellent dispersion. Colloid mills can operate continuously but have a high first cost, high power requirement and a heating effect on the material.

An important type of mixing in the food industry is involved in the packaging of foods in an atmosphere of an inert gas. This is particularly valuable with foods high in fats which are easily oxidized, such as shelled nuts and powdered whole milk. Either water-pumped nitrogen or carbon dioxide is commonly used. The product is packed in a rigid container and partially closed, the air is evacuated and replaced with an inert gas, after which the final closing operation is carried out on the packages. It is frequently necessary to repeat the evacuation and release of the vacuum several times to reduce the oxygen content of the container to a sufficiently low degree. Since whole milk powder when in contact with carbon dioxide will adsorb a considerable amount of the gas, packed containers will develop a vacuum upon storage if sealed under carbon dioxide. This can be sufficient to cause collapse of the can and is usually remedied by utilizing a mixture of nitrogen and carbon dioxide. Ground coffee is customarily packed today under vacuum, though one national brand uses carbon dioxide.

For mixing solids with solids, the double-helix ribbon mixer is quite satisfactory. It is usually operated at moderate speeds. In the manufacture

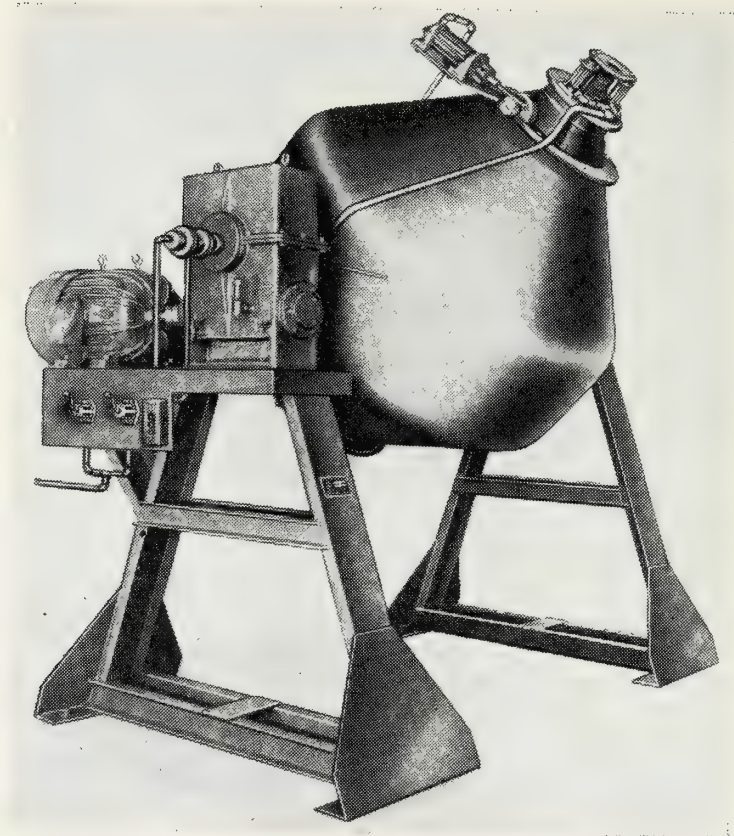


(Courtesy The J. H. Day Company)

Figure 21-6. 1SM-4 Day end discharge-continuous with wipers. Center discharge-cut-out. Center discharge—continuous.

of cake mixes, the helices are connected to the shaft with fine wires at frequent intervals. These serve the purpose of blending the shortening with the dry powder by a cutting action while the material is being turned over. The tumbling-barrel type is simple, but useful in various modifications. The barrel may be mounted at an angle oblique to the shaft to give a gyratory motion to the mix. The double-cone mixer is a variation in form of the tumbler mixer. The inside of such mixers is usually polished and free of obstructions. The angle of repose must be carefully calculated so that the materials may slip rapidly from one cone to the other. Cone mixers are quickly loaded and discharged. This factor of speed, together with rapid mixing and great cleanliness favors wider extension of their use in the food industry. While the Votator, which is described in detail later, is used primarily because of its high heat transfer coefficient it should be noted that it is an effective mixer in processing lard, vegetable fat and ice cream mix.

The selection of a mixer for a given operation requires that the specific result to be achieved be kept constantly in mind. In many instances the agitator may be called upon to perform two or more functions simultane-



(Courtesy Machine Co. of New Jersey)
Figure 21-7. Gemco conical blender.

ously. The selection will depend also on the medium in which the mixer is to operate. The type or types, the dimensions, and the position of the agitator for the operation may be determined from broad empirical principles. The experience of the engineer is important in specifying the correct conditions to accomplish the desired result at economical fixed and operating charges.

Heat Exchange—Heating

The transmission of heat energy to food for the purposes of preservation or sterilization is a subject of major importance to the food engineer. He is interested in attaining his processing objective speedily and economically. Ordinarily the heat required is generated outside and then transferred to the absorbing unit, water vapor or heated water being the most common agent. Factors which affect this flow of heat are: temperature differences, velocities, viscosities, specific heats and the total resistance from heat source to heat recipient.

The transfer of heat for food processing is usually accomplished by either conduction or convection with radiation playing a minor role. Conduction is the transfer of heat from one part of a body to another part of the same body, or from one body to another in physical contact with it, without appreciable displacement of the particles of the body. The rate of heat

transfer by conduction is affected by the thermoconductivity of the food material and will vary directly as the area of the heating surface and the difference in temperature and inversely as the thickness of the substance. For these reasons it is apparent that rapid movement of the liquid past the heat transfer surface will increase conductivity. This principle is taken advantage of in the plate pasteurizer now widely used with liquids for continuous heat transfer. If the substance being heated is high in viscosity, batch treatment is preferable. Efficiency in heat exchange by conductance is improved by applying counter-flow principles; by moving films rapidly on both sides of the heat transfer surface; by thorough mixing of fluid films with the body of the fluids; and by employing the widest possible temperature differential consistent with good control without injury to the product. In the construction of heat transfer equipment it is desirable to use as thin walls as structural limitations permit and to employ metals having high heat conductivity, so as to decrease resistance to heat flow. In calculating heat exchange by conductance the following relationships are involved:

$$\text{Conductance} = U \times A$$

where

U = over-all coefficient of heat transfer in Btu/(hr)(sq ft)(°F)

A = area in sq ft

and

$$Q = \Delta T \times U \times A$$

where

Q = total (rate of) heat flow (in Btu/hr)

ΔT = mean effective temperature difference between hot and cold side

U = as above, and

A = surface available to heat transfer (sq ft)

Usually ΔT may be taken as the arithmetical mean of t_1 and t_2 . But if t_1 is more than twice t_2 the logarithmic mean of the terminal temperatures must be used.

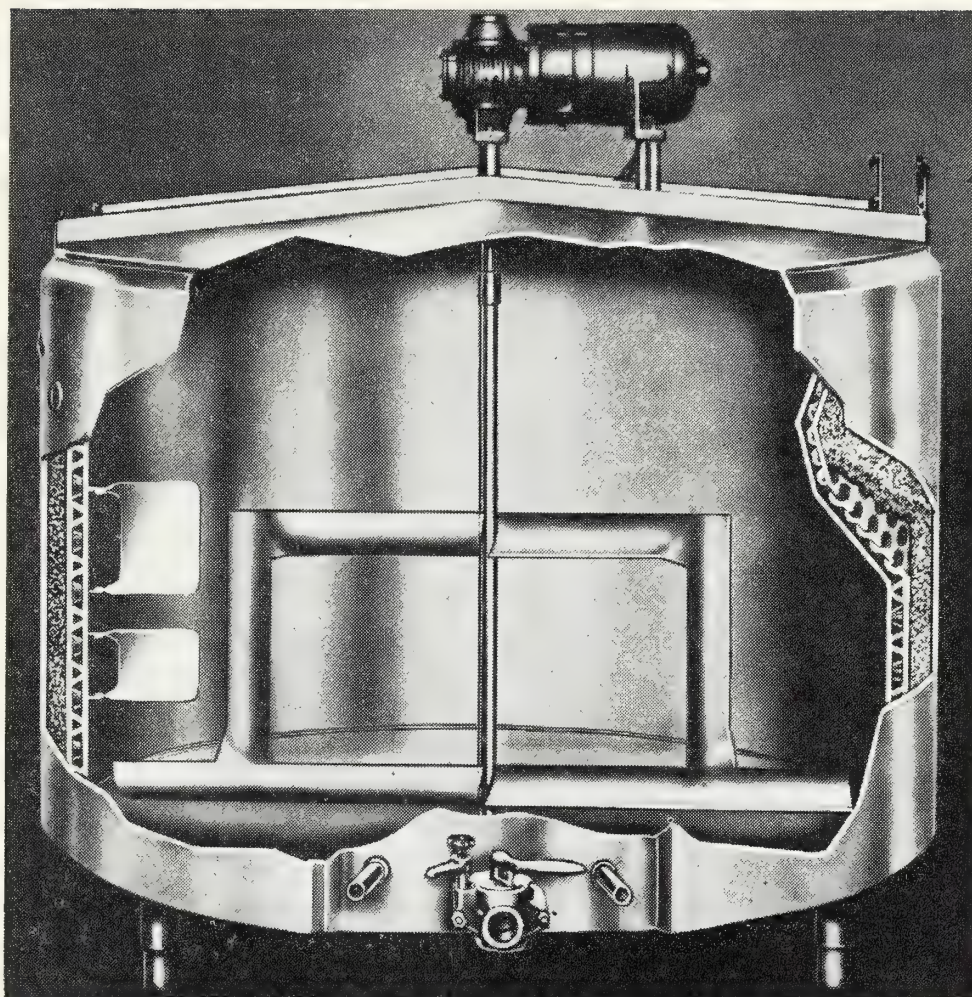
The Votator represents a notable application to fluids of countercurrent flow principles. The heating medium in a jacketed tube moves counter to the product flowing rapidly in an annular space between the cylinder walls and a mutator shaft, equipped with scraper blades rotating at high speeds. Since the shaft occupies approximately three-quarters the diameter of the heat transfer tube, the liquid flows in a fairly thin film. There is a high ratio of surface to the volume of the food material which makes for great efficiency and a high rate of heat transfer. Turbulence within the cylinder is set up by the high speed of the shaft and blades. The scrapers clean the surface hundreds of times per minute, which prevents scorching and local

cooking. This, coupled with high velocities both inside and outside the tube, results in the highest known heat transfer coefficients in the processing of high-consistency materials. For example, in making starch paste for salad dressing continuously, producing 1800 lb/hr, a U of 583 has been obtained when heating the mix from 76 to 196°F. On cooling the thickened mass back to 80°F a U of 316 was realized. This is more than five times the rate that has previously been possible in any other device.

There are a number of other types of heat exchangers used in food processing. The plate type has been most widely adopted in the dairy industry. This equipment consists of a series of thin stainless steel plates of varying design separated by dividers hung on a horizontal frame with flexible gaskets between surfaces. The assembly is similar to a plate-and-frame filter. The heating or cooling medium flows on one side of the separator and the process liquid on the other. The metal plates are stamped with various patterns designed to create turbulence and improve heat transfer. Over-all heat transfer coefficients run from 400 to 500. Plate type equipment is compact, easily accessible and completely closed. It is assembled in sections both in parallel and in series with effective use of regeneration through counter flow of the liquids.

The surface tubular-type heat exchanger is excellent for rapid cooling. It consists of a series of tubes connected vertically with narrow metal strips to make a continuous surface over which a hot liquid flows. Ice water is circulated through the tubes in the upper portion while the lower sections are brine or ammonia-cooled. Such equipment is space saving and easily accessible. While there are loading limits, with 1-in. tubes as much as 600 lb of milk can be cooled from 145 to 35°F per ft of length per hr.

Internal-tubular, double-tube, or tubular heat-exchangers are common throughout the industry. All of these represent a closed system with the liquid food material inside and the heating medium on the outside so that no change in concentration by evaporation occurs. Tubular heaters are not so easily cleaned nor are they as compact or efficient as the surface type. The shell and tube or so-called barrel type is constructed like a steam chest. Vats equipped with a rotating coil-type heat exchanger are very popular in dairies and are useful for many purposes. The coils are rather difficult to clean. Their rotation in the liquid contained in the vat tends to incorporate air. The smooth surface type of vat with circulation of the heating medium through the jacket offers the advantage of low cost, simplicity, and accessibility. Heat exchange efficiency is improved through agitation of the liquid and forced circulation of the heating medium. One advantage of such equipment is the ability to carry on successive operations of heating and cooling in the same vat. Jacketed mixing tanks have infinite adaptations for heat transfer in the food industry.



(Courtesy The Pfaudler Co.)

Figure 21-8. Pfaudler process vat with pressure jacket.

Heat exchange equipment usually produces effects short of commercial sterilization. In pasteurization all pathogenic organisms as well as more than 99 per cent of all micro organisms are destroyed. While the product is safe from a health standpoint it requires refrigeration until consumed. In vat pasteurization of milk the liquid is held at a temperature of 142 to 145°F for 30 min. Similar results can be accomplished in 20 sec at 165°F by rapid flow of the milk through continuous tubular or plate pasteurizers. The rapidity of this latter operation results in retention of the original flavor practically unchanged. Such high-temperature, short-time equipment has made possible continuous sterilization of pumpable foods. In the Martin process by resorting to temperatures above the boiling point liquids are commercially sterilized, continuously cooled and then filled into pre-sterilized containers. This process maintains product acceptability to a very high degree. Vacuum pasteurization of cream for butter making is accomplished by rapid heating of milk to 250°F and flashing the liquid into a vacuum chamber, with resultant rapid cooling and exhausting of undesirable odors. Loss of volume as water vapor is not large in the process. The equipment is known as a Vacreator.

Convection may be defined as the transfer of heat from one point to another within a fluid, gas, or liquid by the mixing of one portion of the fluid with another. In natural convection the motion of the fluid is entirely the result of differences in density resulting from temperature differences; in forced convection the motion is produced by mechanical means. In the sterilization of light liquids in cans the foods are convection heated, while heavier food products are conduction heated. Thermal processing (or canning) of foods is the most widely used method of preservation. It involves the destruction by heat of microorganisms and enzymes after packaging the food in hermetically sealed containers, which may be made of metal, glass, or other materials.

Commercial sterilizing may not result in complete destruction of all bacterial flora but must be sufficient to insure that no growth of residual organisms in the container will occur. In recent years much research attention has been given to the study of heat penetration in cans. The objective has been to reduce the necessary time and temperature employed in sterilization so as to improve flavor and retain nutritive value in the processed food. The literature on this subject is voluminous and should be consulted for detailed information.

In calculating the time and temperature required for processing a particular product in a given-sized container certain data must be determined experimentally. The curve for the temperature rise at the center of the can during heating is plotted from thermocouple readings and a mathematical equation is derived from this curve. The thermal destruction time for the bacteria present is next measured. A curve is again drawn and a second mathematical equation is derived. From these two equations the destruction time at any temperature can be calculated. For convenience the term "sterilizing value," F_0 , has been adopted. F_0 is equal to the amount of lethal heat at the slowest heating point in the can. It is equivalent to the number of minutes of holding necessary at 250°F when no time is required to heat to 250°F or cool to sublethal temperatures and when the thermal death time curve slope (Z) is equal to 18°F. Z value is equal to the temperature differential between two points on the thermal death time curve differing by a factor of 10 on the time scale. The process time will depend on F_0 . Tables of sterilizing values of some commercial processes are available.

Food products designed for thermal processing are cleaned, trimmed, graded and inspected by common operations already described. Hot water or steam scalding is universally used for vegetables. Such treatment, termed blanching, frees the product from adhering materials which might injure flavor during storage and wilts or swells the tissues of an object which permits better control of the filling operation. It destroys enzyme systems

which might affect quality adversely during the bringing-up period. It may also improve the color of the product but does not reduce the thermal death time of bacterial spores. The trend in present practice is to use water temperatures of 190°F or higher to maintain automatic temperature control. The water must be replaced continuously to avoid build up of contamination. The filling of cans is almost universally accomplished in the United States with machines. A few products like sardines, asparagus and whole tomatoes are hand-filled. Machines have been designed which will fill baby food containers at a rate of 1000 units per minute. In canning fruits or vegetables a hot dilute solution of salt or sugar or both is often added immediately after filling.

Exhausting is generally practiced to remove air or gases before sealing the cans. The can contents are heated in a steam chamber or water bath at 185 to 205°F for 5 to 30 min. Alternatively, a vacuum exhaust can be carried out in vacuum chambers with subsequent sealing or solder tipping. For glass jars, particularly for canning baby foods, a jet of steam is introduced just under the lid before it is spun on. This insures the development of a vacuum after processing and cooling. These illustrate various techniques to insure the presence of a vacuum in the hermetically sealed container after the process is completed. It is necessary with large cans to avoid sealing at too high a temperature to prevent subsequent panelling of the sides, due to the vacuum developed.

Cooking involves the shortest possible processing time required to render a product stable against bacterial spoilage. Rotating or rolling cans containing liquid products enhances the progress of heat penetration, and rapid strides are being made in this direction today with the development of end-over-end sterilizers. The resistance of microorganisms to heat depends on the pH of the product. Fruits, fruit juices and such acid products require much less processing or sterilizing than do vegetables and can be sterilized commercially at 160 to 190°F. Such neutral products as vegetables which have been in intimate contact with soil organisms are of generally hard texture and high protein content and require long periods of processing at atmospheric pressure. For this reason they are always sterilized at temperatures above 212°F.

Cooling is necessary to avoid objectionable changes in color and flavor and to avoid over-cooking. The type and extent of cooling are important. For some products where heat does not injure their quality, air cooling may be used. The rate is slow and will be affected by air temperature and movement, as well as the pattern of piling. Water cooling is most common and is usually carried out by slow passage of the loaded crates through a tank, though water sprays are also used. Cans are usually water cooled to about 110°F since the drying of the exterior of the can is still rapid at this tem-

perature. Retort cooling is sometimes employed, particularly with evaporated milk. It is necessary in this operation to balance the drop in steam pressure by introducing air pressure to prevent undue strain which would be exerted on the containers by releasing the pressure. With small cans this is not necessary—water being admitted directly into the retort as soon as the pressure has dropped to atmospheric. For retorting of successive lots there is a thermal saving if the cans are cooled outside of the retort.

Any container for a food product which is to be sterilized must satisfy a number of conditions. It must be sufficiently rigid, though relatively light in weight. It must be susceptible to ready fabrication and easily opened. It must be sanitary and attractive in appearance and without toxic effect on the food. It must be impervious to air and water and able to withstand the heat of sterilization. It must lend itself to hermetic sealing at high speed mechanically and be relatively inexpensive in cost. The heat conductance for water is 0.084, for glass 0.37, while for steel it is 10.8, which emphasizes the greater resistance of glass over steel to heat flow. It is common practice to lacquer tin cans to avoid fruit discoloration or to prevent staining of the tin. Electrolytic plating today requires only 20 to 40 per cent as much tin as the hot-dip process formerly practiced.

Sterilization is normally carried out in vertical retorts measuring 42 in. in diameter and holding 3 crates. The peak consumption of steam in such retorts is 80 to 200 boiler h-p per hr. About 300 lb of steam is used in a common operating cycle of 60 min. Continuous cookers which contain a reel and spiral with adjustable speed are widely used for such liquids as evaporated milk. These greatly shorten the process time but the initial equipment cost is high. Recently developed end-over-end retorts apply the rotating principle to shorten the processing time by as much as 80 per cent. Careful control of the head space in the can is important to obtain good heat transfer by convection in such processing.

Roasting and toasting are the most widely used applications of heating by radiation to be found in the food industry today. Such products as nuts, beans, and corn flakes are processed in this fashion which removes some moisture and destroys enzymes and bacteria. Hot air roasting in cylinders is sometimes used but direct heat roasting with gas jets against the surface of a rotating cylinder is most common. Radiant strip heaters are less common and quite costly in power consumption.

Heat Exchange—Refrigeration

Most foods keep better when stored at temperatures below 50°F. The withdrawal of heat from a body which occurs under these conditions is termed refrigeration when viewed as a unit operation. This is one aspect of the general phenomenon of heat exchange. Reduced temperatures greatly

retard the multiplication and growth of most microorganisms in food materials. At the same time both the enzymatic and nonenzymatic reactions which lead to deterioration and spoilage proceed more slowly. Cold-storage at 33 to 50°F is used for a great variety of food products under many conditions. Demand for space so conditioned as to temperature has led to the widespread erection of refrigerated public warehouses throughout the United States. In these, controlled conditions of temperature and humidity are maintained by means of artificial refrigeration and air conditioning techniques. Fresh fish, fresh meats, milk and cream are highly perishable and must be held under refrigeration at all times, usually at temperatures just above the freezing point. Under the best conditions the storage life of these products is only a few days or weeks, at most. Eggs in the shell and butter in tubs may be carried at approximately 32°F for periods up to one year and remain edible.

Refrigeration may be accomplished by either natural or mechanical means. In the United States natural refrigeration through the use of ice is still used for such purposes as protection of freshly caught fish, for the icing of lettuce during transit, and for the bunkers in the modern refrigerator cars which have made possible country-wide marketing of fresh meats, fruits and vegetables. The development of artificial refrigeration through mechanical compression or adsorption systems has made possible the application and control of heat withdrawal to foods under conditions varied at will. This is a highly specialized branch of engineering.

Refrigerating systems are rated as to their capacity in tons. A ton of refrigeration is equivalent to the removal of 288,000 Btu in 24 hr, or 12,000 Btu per hour of continuous operation. The rating of ammonia compressors in standard tons assumes that the ammonia gas enters the system at 5°F and leaves at a pressure equivalent to saturation at 86°F. In calculating refrigeration loads and capacities, the engineer must consider the initial cooling and heat losses, as well as the continuous radiation loss through the walls. In addition, he must recognize that the heat of respiration of fresh vegetables and fruits in storage is a part of the refrigeration load, and make due allowance for it.

The limit of good eating quality for foods carried in refrigerated storage varies and rarely reaches a maximum of one year, but foods frozen at -10 to -15° will generally store well for a year or longer, if held at 0°F. Artificial freezing of poultry and meat dates back 75 years but the general commercial application of quick-freezing to foods is a development of the past 25 years. In the last decade the growth of the frozen food industry in the United States has been phenomenal. The first efforts at quick-freezing of foods failed to take into account the necessity for initial high quality in the raw material. Even today the flavor and texture of quick-frozen foods

varies considerably from brand to brand and lot to lot. Whatever system of quick-freezing is used, it is necessary to produce ice crystals so small that there will be a minimum change in the structure of the cells. This will keep the separation of water as ice to a minimum, and quickly arrest biological activity. When properly carried out, no other form of preservation will retain the original characteristics of freshness and flavor appeal for as long periods of time as does quick-freezing.

Before the advent of fast-freezing, good flavored citrus fruit juices were available only when the fresh fruit was in the market. With the development of a system of low-temperature concentration for fruit juices which maintains natural flavor during removal of one-half the water content, it became economically sound to distribute frozen fruit juices. Frozen orange juice concentrate has become so popular that 30 per cent or more of the Florida citrus crop is now used in its manufacture. Frozen concentrated grape juice has met with wide acceptance. On the other hand, tomato juice develops its typical flavor as a result of heat processing. In consequence, frozen tomato juice concentrated at low temperature fails to satisfy consumer tastes. Even the citrus juices profit in keeping quality by flash-heating to 190°F. It is customary in the industry today to use Votators for continuous slush-freezing of the concentrates, which are then canned and rapidly frozen solid with an air blast at -20°F or lower. Alternatively the canned juice is chilled and frozen by immersion of the tins in cold alcohol solution. The food engineer must consider the factors affecting heat transmission in tins to obtain a high over-all heat transfer coefficient in this operation.

The freezing of ice cream makes up an important segment of the frozen food industry. The annual consumption of it in the United States is between 3.5 and 4 gal. per capita. In its manufacture a mixed solution of sugar, skim milk, butter fat and a stabilizer is frozen and whipped to incorporate air and obtain a smooth texture in the hardened product. The presence of high percentages of soluble solids lowers the freezing point to approximately 27.5°F. As freezing takes place, the sugars concentrate in the liquid phase with an accompanying large increase in viscosity. The frozen mixture of air and liquid is drawn from the freezer when stiff but plastic. The liquid in ice cream is never completely frozen at the temperatures usually obtained. It is estimated that at -22°F only 90 per cent of the water would be frozen. The calculation of refrigerating requirements for ice cream is difficult because of the character of the mix. The refrigeration load in a freezer is due to the heat from cooling of the liquid, the radiation losses, and the heat equivalent of the energy expended in the agitation. The control of volume increase or overrun in ice cream is important to the eating quality and flavor. In the continuous freezers, such as the Votator,

the mix and air are introduced under a controlled positive pressure which assures a standard volume when frozen. It is essential to harden the ice cream quickly after packaging in order to avoid melting. The more rapid this operation the smaller the size of the ice crystals formed and the smoother the texture.

The frozen egg industry is very large in volume. The trend today is toward the pasteurization of both whole eggs and yolks prior to freezing. This process requires 3 min at 142°F for whole eggs and 2 min at the same temperature for yolks. The pasteurized liquid egg is packed in 30-lb tins, sharp frozen to 0°F and held for at least 44 hr at this temperature. Freezing time can be desirably shortened by lowering the freezing room temperature to -20°F.

In freezing fruits and vegetables the cellular tissue tends to break down regardless of the rate of freezing. Quick-freezing is advantageous, since it reduces the quality deterioration which could occur due to enzymatic or bacterial changes during the first phase of the freezing process. Better quality is obtained with many fruits by siruping them before freezing. This procedure is used with strawberries, raspberries, apricots, peaches and cherries. The addition of the sugar reduces the undesirable changes occurring in the fruit during freezing for storage and thawing for use. The browning of peaches as a result of oxidative changes is prevented by small amounts of ascorbic and/or citric acid added to the sirup. The quick-freezing of vegetables is a great time saver for the housewife. Freezing produces an effect equivalent to a precooking, so that the thawed vegetable can be adequately prepared for the table with 4 to 6 min boiling. Most vegetables are blanched before freezing to retard enzymatic changes. The maximum storage life of most frozen vegetables is about one year at a storage temperature of -5°F. There is a steady flavor deterioration during this period, which is paralleled by a continuous loss of vitamins.

Many types of quick-freezing equipment are employed. In blast freezing the air in the freezing room is cooled as low as -40°F and circulated at high velocity with powerful blowers. In some modifications tunnels are used to confine and direct the air flow over the product carried on a moving belt or screen or loaded onto trucks. In one application in the ice cream industry a cylinder or ribbon of ice cream is extruded continuously from a freezer and cut into small portions which pass through such a blast tunnel for hardening prior to individual wrapping. When the food product is frozen by direct contact with the freezing liquid the process is termed immersion freezing. Salt-and-ice mixture, low-temperature brine and even chilled sugar sirup are used. The freezing liquid may alternatively be sprayed onto the product, which in some applications is packaged in small units prior to submersion.

Today the equipment used most extensively in the quick-freezing of household size containers of food is of the multiple plate type invented by Birdseye. In this freezer a number of hollow plates of corrosion-resistant metal are so mounted horizontally that the space between them is adjustable. These plates or shelves are loaded with the sealed packages of prepared foodstuffs and are then moved together by hydraulic pressure to bring the layers of packages intimately in contact with the plate surface. Spacing bars between the plates prevent distortion of the containers. The insulated cabinet enclosing the plates is now closed and the refrigerant circulated through passages in the plates. Heat is thus conducted away from the food rapidly until frozen.

The distribution of frozen foods requires maintenance throughout the cycle of low-temperature conditions to prevent thawing. Since foods contain living microorganisms, even when conditions of handling are ideally sanitary, bacterial growth can progress after defrosting and is favored by the breakdown in cell structure which inevitably accompanies the freezing process. Products which have been permitted to thaw and are then refrozen may give rise to food poisoning and, at the best, will suffer in eating quality and possibly in nutritive value.

For bulk transportation of frozen foods specially insulated refrigerated trucks and cars are employed. For small quantities solid carbon dioxide affords adequate protection in transit. Temperatures should not be allowed to rise above 0°F if reasonably good storage life is to be expected from the frozen food. Refrigerated display cabinets in retail food stores are commonly left open for the convenience of customers, a practice which necessitates rapid turn-over of stocks to avoid dangers arising from partial thawing.

An illustration of the commercial freezing process for consumer packages of green peas is given in the following outline:

Peas—Thomas Laxton, Dark Skin Perfection, Wyola—maturity determined with aid of Tenderometer

Harvesting—mowing, loading and trucking to station for vining; time selected by field man; some field vining

Milling, Weighing and Boxing—air blast cleaning and screening (may occur at plant), loading into lug boxes for transporting, with chilling with cold water or chipped ice when necessary

Washing—any combination of immersion, spraying, flotation, etc.

Blanching—at 200°F or above for 50 to 120 sec to inactivate enzymes; inactivation of catalase a convenient indicator

Inspection and Quality Grading—on moving belts and by brine flotation according to specific gravity

Cooling—in water to 60°F or lower

Filling—final inspection and filling into various types of waxed paperboard cartons; automatically formed, filled and closed

Freezing—in multiple-plate or other type of freezing equipment; some loose freezing and subsequent filling

Cartoning—in corrugated fiberboard boxes

Storage—at 0°F or lower awaiting shipment. For institutional pack, peas are also frozen on wire belts and subsequently packaged in 3-lb cartons.

While freezing of fresh beef and pork is practiced to some extent, the frozen product has a limited life. Pork may keep 4 to 6 months, beef somewhat longer. The stability of the fat is the most severe limiting factor. Desiccation during freezing in sharp-storage or air blast results in freezer burns. During storage at 0°F or lower the meat must be protected against desiccation by packaging providing good barrier to moisture-vapor transmission. Upon thawing, the meat often drips. This is particularly characteristic of beef.

In contrast, the freezing of poultry pieces has grown into a very large food processing industry. About half of the volume is in broilers weighing under 2½ lb. Common practice is to conduct the freezing in air blast rooms at temperatures as low as -20°F. It is necessary to handle the poultry dressing rapidly to avoid visceral taints. The growth in volume of frozen whole eviscerated poultry has not been so rapid. Warm evisceration is favored and quick-freezing should take place at once. The poultry must be packaged in moisture-vapor proof material and held at temperatures below 0°F. Under the best conditions its keeping quality is as good as that of poultry frozen in the round.

Fish are extremely susceptible to spoilage. This results from bacterial action, from oxidation of the fat, and from enzymatic changes. One of the first applications of quick-freezing methods was made to fish in efforts to delay such spoilage. Salt-water fish are commonly packed in ice in the trawlers as soon as caught, a practice which only delays the rate of deterioration. The U. S. Wildlife and Fishery Service has fitted two trawlers experimentally with refrigerating equipment to carry on freezing at sea in North Atlantic waters. In one of these, the fish are frozen in the round and glazed as soon as caught. When port is reached, the fish are thawed, filleted and quick-frozen in small packages. A second trawler has been fitted to do the filleting, packaging and quick-freezing at sea, an operation which considerably improves the quality of the frozen fish. Immersion-freezing was originally used for freezing fish by direct immersion into a mixture of ice and salt, or brine. In a modification of this method, the freezing brine was sprayed on the product. It is more usual today to use the metal contact type of heat exchange equipment.

A recent development in refrigerated foods is the process of dehydro-freezing in which the product is partially dehydrated before freezing. This reduces the bulk and permits a combined operation of thawing and re-

hydration in boiling water at the time of use. Increased cost of such processing is likely, in most instances, to offset the advantage of smaller bulk.

Evaporating

Evaporating as viewed by the food engineer is a form of heat exchange concerned with the concentration of liquid food materials. While usually carried out at reduced pressures in modern factory practice, the operation can be performed under atmospheric conditions. Solar heat is used for the evaporation of sea water from shallow ponds for salt production. Boiling from open kettles is the oldest form of evaporation, but usually causes undesirable changes in the flavor, color and chemical state of food materials being concentrated, an effect which can be greatly lessened by carrying out the process under reduced pressure. Direct heating may be desirably applied to open kettles as in the concentration of sugar in sugar boilers, or in the manufacture of apple butter. In the food industry, steam-jacketed kettles, commonly constructed of sheet copper, are still used for concentrating small batches, particularly in the confectionery industry, in the manufacture of mincemeat, and in the production of fruit jam. Such kettles are usually only jacketed part way up the sides to avoid scorching of the foam on the sides of the pan.

A steam-jacketed evaporator is an apparatus of varying design for concentrating liquids. In it a reduced pressure is maintained in the boiling chamber, with heat being transferred to the liquid by means of a steam-heated jacket, coils, or chest. The evaporator has a large opening at the top, connected to a vapor-condenser, a noncondensable gas ejector, and a source of vacuum. Various classes of condensers are used for liquefying the vapors and removing the condensate. A surface condenser is one in which a metal surface separates the cold water and the vapor to be condensed. A jet condenser is one in which water and vapor are in direct contact. A wet condenser removes both air and hot water with the same pump, while a dry condenser separates gases only. A barometric condenser is one set sufficiently high that the water drains from it by a barometric hot leg into a sealed tank or hot well, while a low-level condenser requires a pump to remove the hot water.

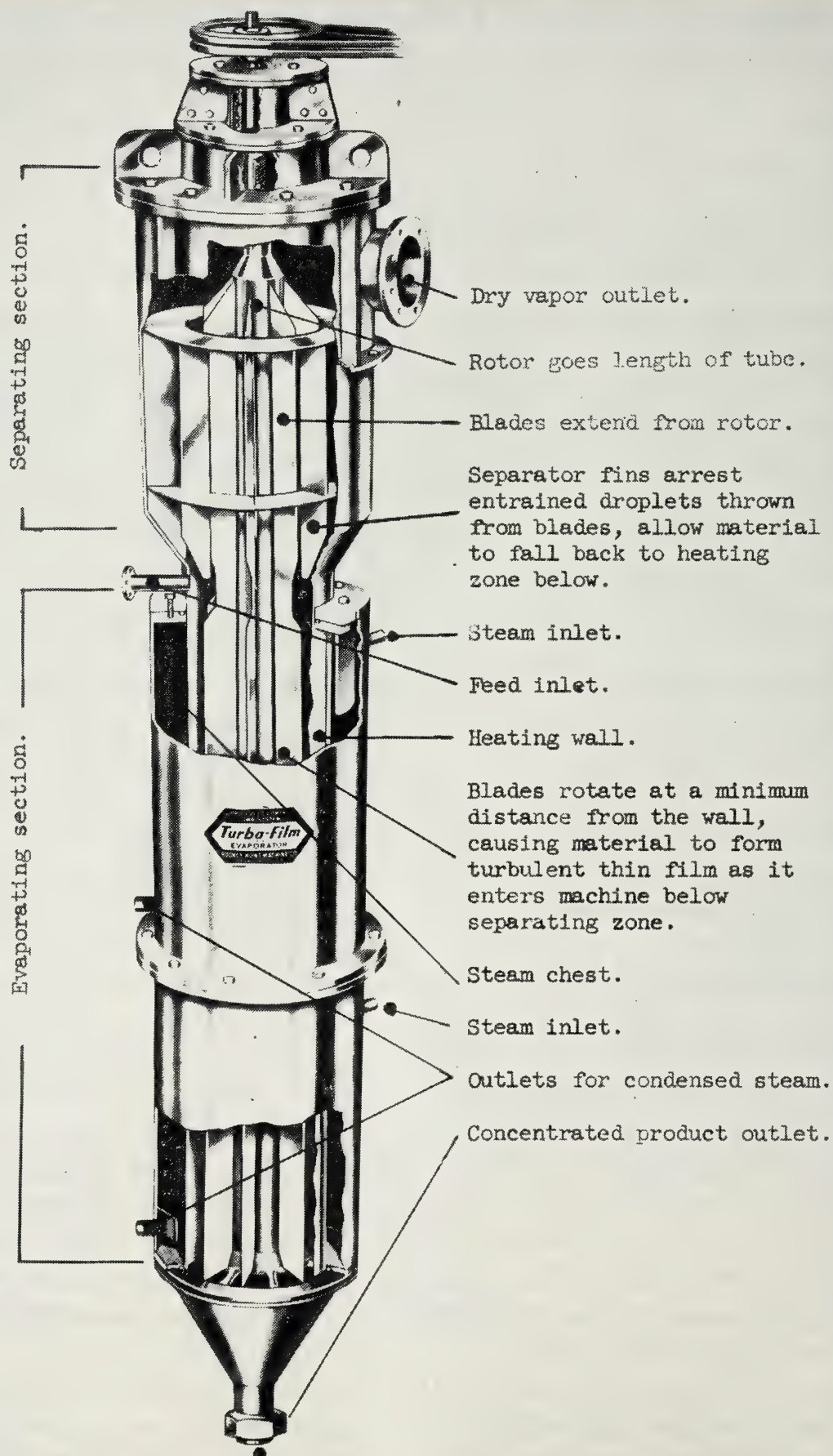
For the removal of air reciprocating vacuum pumps or Nash pumps with Corliss-type valves are common, and are cheaper to operate than steam-jet ejectors for vacuums up to 24 to 25 in., particularly since the exhaust steam can be returned to the evaporator. Steam-jets have the advantage of greater simplicity and freedom from moving parts, as well as being cheaper to install. On the other hand, they require more steam per pound of air removed from the evaporator than do reciprocating pumps, as the steam discharge cannot be re-used.

Evaporators are classified as single-effect or multiple-effect. The standard single-effect evaporator consists of a vertical cylindrical shell with coils positioned across the interior horizontally. It is sometimes called the calandria type, although the word calandria properly used refers to the heating element of any evaporator. In the Kestner type there is natural circulation through relatively long tubes in which the liquid being concentrated is on the inside. The feed is introduced at a fixed rate and is all discharged after passing upward through the tubes. In the forced circulation evaporator, the liquid is pumped repeatedly through the tubes with a positive velocity. As built by Mojonnier and Blaw-Knox these have a separate calandria section and evaporation chamber. This type gives very high heat transfer coefficient. While the relative cost of forced circulation evaporators is higher than for horizontal tube evaporators of the same size, this design is especially suitable where the liquid being evaporated is viscous and where expensive structural material such as stainless steel must be used for the heating surface.

In calculating the size of evaporators required, the engineer must compute the total heat units expended per pound of water to be evaporated. This will be made up of the sensible heat required to raise the liquid to the temperature of the evaporator, the internal latent heat required to convert the water to vapor at the same temperature, the external latent heat to supply the energy expended by the vapor because of the increase in volume under reduced pressure, and the thermal equivalent of the vacuum pumps. Then, knowing the pounds of water to be removed per hour and the temperature of the steam, it is possible to compute the heating surface needed in the evaporator.

The coil-type of single-effect evaporator is still widely used in the food industry for concentrating such products as milk, gelatin, sugar and fruit juices. But the tubular type with forced circulation is finding increasing favor because of its greater speed and the reduction of cooked flavor. Single-effect evaporators ordinarily operate at 125 to 140°F but can be carried as high as 240°F. Such heat-sensitive liquids as orange juice suffer flavor loss at even the lower of these temperatures. The development of special evaporators, using recompression and operating at a temperature of 60 to 80°F, minimizes the flavor loss in orange juice and has made possible the five-fold and six-fold concentration necessary for economical marketing of frozen concentrated juice.

A multiple-effect evaporator is a series of evaporator bodies so connected that the vapor from one body is the heating medium for the next body. Each successive reuse of the vapor is termed an "effect." Passing from single-effect to multiple-effect operation decreases steam cost but increases apparatus cost. An elevation of the boiling point occurs with each effect,



(Courtesy Rodney Hunt Machine Co.)

Figure 21-9. Cut-away view of Rodney Hunt Turba-Film evaporator.

and imposes a practical limit on the number possible to use. The purposes of employing vacuum in evaporators are two-fold; (1) to increase the available temperature difference; and (2) to protect liquids that would be damaged by high temperature. As the vacuum increases, the boiling point decreases very rapidly and, therefore, the available temperature difference increases. It is possible, however, to operate with so high a vacuum that the decrease in heat transfer coefficient more than offsets the increased temperature differential. With many food materials which are sensitive to heat, it is desirable to employ the highest vacuum possible to preserve the quality of the product even though at the expense of decreased capacity of the evaporator. This is another example of how flavor acceptability may limit engineering practice.

Recompression evaporation has been successfully developed in recent years and applied to the concentration of such liquids as citrus, apple, grape and sugar juices, milk, liquid egg, and pectin solutions. In such systems, heat is transferred from the exhaust water vapor to another vapor of low specific volume, which is then compressed. If water is evaporated from orange juice at a temperature of 60°F, its vapor will occupy 1208 cu ft/lb. If its latent heat is exchanged with ammonia boiling at 45°F, the water vapor will be condensed and the ammonia vaporized. Since ammonia vapor has a volume of only 7.2 cu ft/lb, it can be compressed inexpensively from a temperature of 45 to 100°F. The condensed ammonia is again vaporized at 45°F thereby cooling the water vapor until it condenses, after which the cycle is repeated. A down-flow evaporator design is employed to provide rapid concentration and a short exposure of the orange juice at an extremely low temperature. Recompressing such as in the Skinner evaporator consists of ejecting evaporated water with live steam and sending the exhaust to the jacket of the evaporator.

One other application of evaporation which finds a limited use in the food industry is distilling. For the separation of such materials as fatty acids, esters and vitamins which have a high molecular weight, materials of extreme purity can be obtained with high vacuum stills. These may be fitted with centrifugal-type condensers or with differential condensers and successive evaporation of the return liquid.

Drying

Drying means the removal of a liquid from a solid by thermal means and differs from evaporation processes mainly in that the latter utilizes different equipment which removes much larger quantities of liquid per hour than do drying processes. When applied to foods the term dehydration has been widely adopted and the operation is used to reduce the water content so low that enzymes become inactive and microorganisms are unable to grow.

Other objectives are to lower shipping costs through weight reduction and to preserve the food product during storage and shipment. When applied to foods the term "dried" is commonly used for products from which the moisture has been removed by partial drying, either naturally or artificially, usually to a point not below 20 per cent residual. The term "dehydrated" is loosely applied to food products dried by artificial means, usually to moisture contents below 10 per cent. Such classifications are quite arbitrary and are by no means clear-cut.

A few definitions of terms applicable to the drying operation will aid in understanding a discussion of dehydration. The constant rate period is that drying period during which the rate of water removal per unit of drying surface is constant. The falling rate period is that drying period during which the instantaneous drying rate continually decreases. Critical moisture content is that obtained when the constant rate period ends. Humidity denotes the amount of water vapor actually present in a gas. Absolute humidity is the quantity of water vapor in moist air, expressed as pounds (or grains) of water vapor per pound of dry air. Saturated humidity is the weight of water vapor that one pound of dry air can contain when the partial pressure of water vapor in the air is equal to the vapor pressure of water at that temperature. This corresponds to the dew point. Relative humidity is the ratio of the actual partial pressure of water vapor in the air to the vapor pressure of water at the same temperature. Humid heat is the quantity of heat required to raise the temperature of one pound of dry air, plus whatever water vapor it contains, by one degree Fahrenheit and is equal to the heat capacity of water vapor times the absolute humidity in pounds per pound dry air. Humid volume is the volume, in cubic feet, of one pound of dry air plus whatever water vapor it contains, while saturated volume is the humid volume at saturation. Moisture content is usually expressed as moisture quantity per unit weight of the dry or wet solid. Dryer efficiency is that fraction of the total heat supplied by fuel which is utilized in the evaporation of water. Equilibrium moisture content is that amount of moisture in a given material which will neither increase nor decrease under specific conditions of air temperature and humidity.

When a solid dries, two basic and simultaneous processes occur. These are the transfer of heat to evaporate liquid, and the transfer of mass as internal moisture and evaporated liquid. The rate of the drying process is determined by the rate of each process. In commercial dehydration, heat transfer may be carried out by convection, conduction, radiation or some combination of these. In the process, heat must flow first to the outer surface and thence to the interior of the solid. In the operation, mass is transferred as (1) liquid and/or vapor within the solid, and (2) vapor from wet

surfaces. Differences in dehydrating equipment arise from the methods of heat transfer used. Regardless of the equipment, drying in all commercial dehydraters is carried out under controlled conditions of temperature and humidity to a specific end point. The volume, temperature and relative humidity of the drying gas and the surface of moist material exposed will govern the drying efficiency.

Wet-bulb thermometry rather than dew point measurement is almost universally relied on for controlling dehydrater operations. Such control depends upon the observed fact that, when exposed to a current of air, the evaporation of water from a moist object cools it as well as the air flowing past it. Hence, the drier the air, the greater will be the amount of cooling. Measurements of temperature are made by exposing two similar thermometers to the air stream in the dehydrater, the sensitive bulb of one of these being kept constantly moist with water. The difference in reading between the two thermometers is commonly known as wet-bulb depression. In measuring wet-bulb temperatures the thermometer should be kept continuously moist with pure water. It must be located so as to minimize radiation effects, and it must be placed in an air stream having a velocity of 1000 ft/min or more. It is common practice today in specifying conditions for the dehydration of fruits and vegetables to state these in terms of wet- and dry-bulb temperatures. The humidity calculated from wet- and dry-bulb measurements can be read directly from a humidity chart. Such a chart contains plots of absolute humidity, heat of evaporation, wet- and dry-bulb temperatures, relative humidity and dew point.

The wet-bulb depression will determine the maximum evaporating capacity of the air. Actually, the evaporative capacity of a dryer depends upon the conditions maintained. It is good practice to keep below the safety limit, since this gives a better rate of drying without condensation. Usually a temperature differential of 15°F is maintained between the hot end and the cool end of the drying tunnel. In order to save heat, recirculation and reheating of the air is commonly practiced, the usual proportion by volume being 50 to 75 per cent. Additional heat is required since the recirculated air has reached a higher humidity input than if all fresh air is used. In addition to the theoretical quantity of heat required for evaporating a pound of water of the food material, allowances must be made for the considerable heat loss through the walls and in the exhaust air. The characteristics of the material to be dried will vary from one food product to another and affect their drying behavior. While calculated drying rates may furnish a general guide, the only satisfactory procedure is to use a small batch dehydrater and make a number of test runs with the material in hand. Careful observations of the effect of such variables as temperature, humidity, air velocity, tray loading, and size of pieces must be recorded.

Types of dehydraters for solid foods may be tray, tunnel, kiln, rotary or vacuum. Kiln dryers are direct batch dryers of low production rate generally used for low-cost products such as evaporated apples. They are two-story structures with a heater located below a slotted floor. They are characterized by long drying time and unsteady-state operation. Drying is by convection and involves high fuel and labor costs. The design is simple to build and operate but the product is nonuniform.

Tray and compartment dryers consist of a well-insulated enclosure, integral fans and heating coils, and suitable tray supports for the material. Satisfactory operation requires maintenance of constant temperature and an uniform air velocity over the drying material. Such cabinet dryers are generally expensive to operate and find application when the capacity involved does not exceed 50 to 100 lb/hr of dry product. Heat transfer is effected by heated air moving across the exposed surfaces of the wet material at a velocity of 200 to 1000 lineal ft/min. The constant drying rate is determined, principally, by the rate of heat transfer by convection according to the following equation:

$$\frac{dw}{d\theta} = \frac{h_t A \Delta_t}{\lambda} = kg \cdot A \cdot \Delta_p$$

where

$\frac{dw}{d\theta}$ = drying rate, lb water/hr

h_t = total heat transfer coefficient, Btu/(hr)(sq ft)(°F)

A = area of heat transfer and evaporation

λ = latent heat of evaporation at t_s , Btu/lb

kg = mass-transfer coefficient, lb/(hr)(sq ft)(atm)

$\Delta_t = (t_a - t_s)$ where t_a = air temp., °F, and t_s = temperature of surface of evaporation, °F

$\Delta_p = (p_s - p_a)$ where p_s = vapor pressure of water at t_s and p_a = partial pressure of water vapor in the air, atm

Under the conditions stated t_s is the wet-bulb temperature of the air and p_s is the vapor pressure at this temperature and h_t becomes h_c .

Then

$$h_c = 0.0128 G^{0.8}$$

where

G = mass velocity of dry air, lb/(hr)(sq ft)

Whence

$$\frac{dw}{d\theta} = \frac{0.0128 G^{0.8}}{\lambda} (t_a - t_w)$$

where

t_w = wet-bulb temperature, °F.



(Courtesy Proctor & Schwartz, Inc.)

Figure 21-10. Two-stage single conveyor dryer for yeast.

Thermal efficiencies of this type of dryer usually are low and when drying to very low moisture contents may be of the order of 10 per cent. Labor costs are high.

Tunnel dryers are essentially several batch dryers in series. Stacks of trays measuring 3 x 6 ft, usually 20 high, are mounted on trucks or dollies and pushed into a tunnel approximately $6\frac{1}{2}$ ft in width by 7 ft high. When loaded with wet material these move progressively and, in some cases, continuously through the tunnel, which may vary from 50 to 100 ft in length. Air may flow in one pass through the tunnel in the line of truck movement without reheating [adiabatic operation.] Heat may be supplied by hot gases from gas or oil burners or from steam heated coils. Air flow may be parallel or countercurrent to the material flow or a combination in the so-called center-exhaust tunnel may be used. In the latter there is parallel flow in the first portion and countercurrent in the second, the exhaust gases leaving at the point at which the change-over occurs. Center-exhaust tunnels have heaters and fans installed near each end and frequently are supplied with a movable partition to deflect air flow. This type is the one most widely used today in vegetable and fruit dehydration, because of the recirculation feature, which saves heat and effectively controls the wet-bulb temperature of the circulating air.

For estimating the approximate heat consumption of tunnel dehydrators the following formula may be used:

$$F = 1,250 \left[r + (1 - r) \frac{t_1 - t_0}{t_1 - t_2} \right]$$

where

F = heat to be supplied, Btu/lb water evaporated

r = proportion of air recirculated

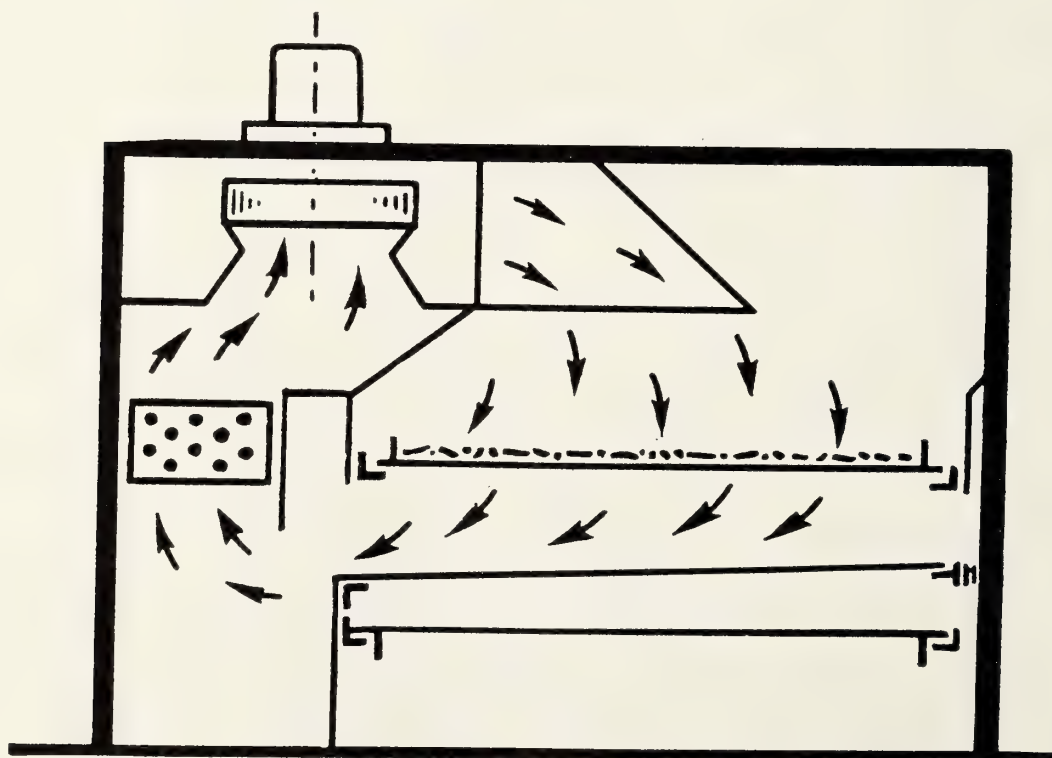
t_0 = temperature of make-up fresh air, °F

t_1 = temperature of air mixture at hot end, °F

t_2 = temperature of air mixture at cool end, °F

1250 = coefficient of change in temp. per .001 increase in absolute humidity (5°F), divided by .001 to convert to lb water evap./lb air, multiplied by 0.25 (approx. humid heat of circulating air)

If $r = .743$, $t_0 = 60^\circ\text{F}$, $t_1 = 165^\circ\text{F}$ and $t_2 = 137.5^\circ\text{F}$ the heat required is 2,150 Btu/lb water evaporated. If the flow of air is 2000 lb/min evaporation will be 20 lb of water per minute, requiring 2,580,000 Btu/hr to be supplied. If no recirculation of air were used the heat input would be more than doubled. For this reason, as well as the prolonged time in the falling rate period it is customary to remove the product from parallel flow tunnels when its moisture content has been reduced to 10 per cent. Drying is subsequently completed in a bin-type dryer. Sometimes a



(Courtesy Proctor & Schwartz, Inc.)

Figure 21-11. Cross-section of a conveyor dryer.

parallel-flow dehydrater is used for the first stage, the material being transferred to a counter-flow tunnel for completion of the drying.

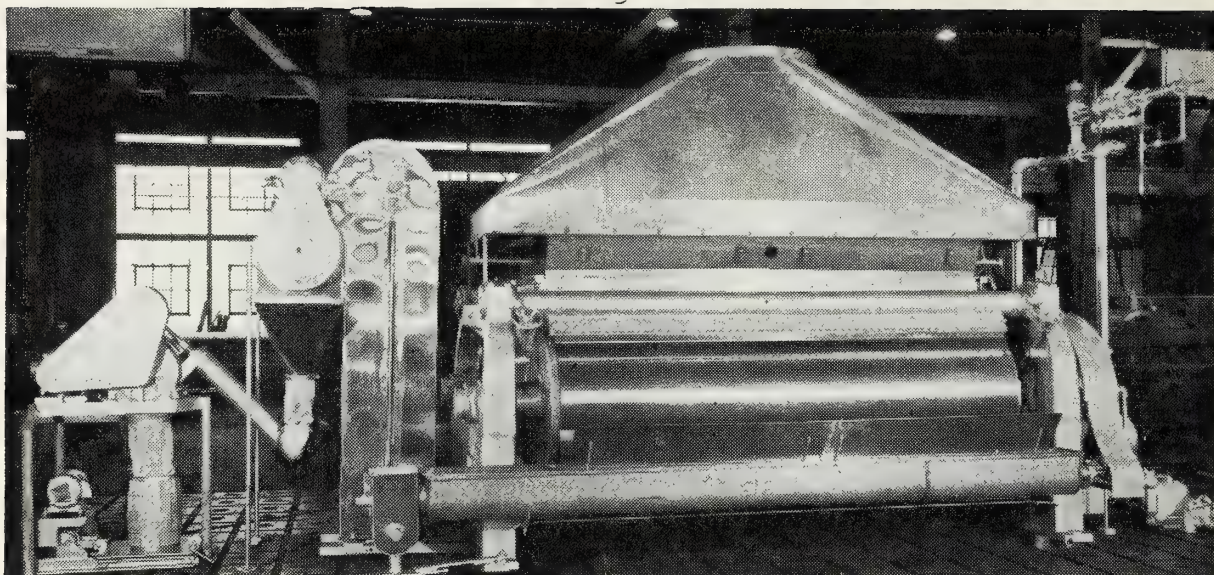
Rotary dryers are limited in their applications to foods though widely employed in the chemical industry. Starch is dried in steam-heated hot-air rotary dryers to a moisture content of about 11 per cent. Citrus and apple wastes are dried in direct rotary dryers.

Vacuum-shelf dryers are indirect batch dryers consisting of a vacuum-tight chamber, heated supporting shelves or platens within the chamber, a vacuum source and a condenser. If constructed of cast-iron the chamber is square, while steel chambers may be either square or cylindrical. They are provided with doors fitted with a pliable gasket. A heating medium is circulated by means of headers to hollow metal platens permanently fastened inside the chamber. The food material is spread on solid metal trays or pans which rest on these platens. Vacua of 20 to 29 in. Hg are employed with an over-all heat-transfer coefficient in the order of 1 Btu/(hr)(sq ft tray surface)(°F temp. difference between heating medium and solid). Drying time is proportional to between the first and second power of the depth of loading, which is generally less than 1 in. Such dryers are suitable for handling small batches of heat-sensitive or easily-oxidized food materials, especially if the labor cost involved is an insignificant fraction of their value.

Vacuum freeze dryers remove water by sublimation and are operated under pressures as low as 0.1 to 2 mm Hg. Such drying is carried out at temperatures below which chemical change usually occurs and loss of volatile constituents is minimized. Denaturation and dimensional shrinkage are avoided. Bacterial and enzymatic activity is stopped and case-hardening does not occur. Heat transfer results from a combination of conduction and radiation but the rate is low. No commercial application has been made to solid foods in the United States, it being estimated that the drying cost for drying meat would amount to \$0.22/lb.

Vacuum dryers have been applied to the continuous low-pressure drying of liquids. Instant coffee is dehydrated from highly concentrated extract carried on an endless stainless steel belt passing over two rotating drums. One is heated for drying and the other is refrigerated to cool the dry product. Radiant heat from infrared strip heaters gives auxiliary drying. The dried product is taken out of the horizontal cylindrical housing through an air lock device. An absolute pressure of 3 to 6½ mm Hg is maintained in the system. Large-scale equipment of this type for the drying of 58 per cent solids orange juice is currently being installed in Florida.

Another application to liquids of vacuum drying equipment is made in the production of malted milk. The mixture is first concentrated in a conventional single-effect evaporator and then transferred to a shallow vacuum pan equipped with rotating heavy-duty blades. The dough-like mass is



(Courtesy Blaw-Knox Co.)

Figure 21-12. Bufllovak atmospheric double drum dryer (42" x 120" drums) used for drying milk. Equipped with stainless steel conveyor, elevator and barrel filter.

scraped from the jacketed heated sides and bottom as the remaining water is removed with a vacuum pump to keep the temperature low enough to prevent scorching.

Drum dryers are widely used in the food industry for the dehydration of a variety of liquids. A revolving heated metal drum conducts heat to the wet surface film to evaporate the water during a partial revolution of the cylinder. A stationery blade called a "doctor knife" scrapes the dry material from the drum. These dryers may operate at atmospheric conditions or under vacuum. They may consist of single rolls, double rolls or twin rolls. The thickness of film and the concentration of the liquid or slurry will control the final moisture content. Distribution of feed to double drum dryers may be effected by means of a perforated horizontal pipe, a suspended swinging pipe or a trough with serrated edges. For other types of drum dryers the liquid may be picked up by dipping in a reservoir below the drums or by splash or spray feeding from beneath or a transfer roll may be used. For heat-sensitive liquids the drum dryer may be encased in a vacuum chamber. Dehydration then results at lower temperatures with a more soluble end product and at a faster rate. The operation is complicated by the vacuum condition and the equipment requires a high initial outlay of capital.

In spray drying the liquid material is highly dispersed in a high-temperature gas zone. This operation involves atomization of the liquid, mixing of the spray with gas, and drying of the liquid drops. The equipment consists essentially of a drying chamber, a source of hot gases, a means of atomizing the liquid, and a method of separating the entrained dry product from the exhaust gases. Spray dryers may operate with concurrent or countercurrent

gas flow and for foods the inlet air is commonly heated with indirect steam. With perfect combustion either gas or oil burners may be used to heat the air directly. Inlet temperatures up to 400°F are common. Atomization is accomplished by high-pressure nozzles, two-fluid nozzles or high-speed rotating disks. Nozzles are favored in the food industry, being operated with pressures of 100 to 6000 psi. Orifice size varies from 0.013 to 0.15 in. in diameter. The particle-size distribution may be varied considerably through adjusting the concentration of the liquid, the diameter of the orifice and the pump pressure.

The rapidity of drying and the low temperature produced at the droplet surface through evaporation gives a spray-dried product which is easily soluble and one which retains naturalness of flavor. Unless destroyed by prior heat treatment spray-dried foods retain a high degree of bacterial and enzymatic activity. One of the principal advantages of spray drying is the production of uniform spherical particles. For economical operation various types of chambers have been suggested. These may be conical, rectangular or silo-shaped. In all cases the engineer must correlate carefully the dimensions of all flues, conduits and blower fans to balance rapidity of drying with high utilization of heat and low entrainment of solids in the exhaust gases. Total heat requirements are made up of the sensible heat of the water evaporated, the latent heat of vaporization, heat in the dry solids and radiation losses.

Another method for drying liquids which is of minor importance is dehydration in a stream of heated air. This has been applied to a heavy paste of concentrated milk spread on a perforated belt moving through a tunnel with countercurrent flow of heated air. The dried material is porous and the albumen uncoagulated, which insures rapid and complete solution upon rehydration. Wet starch is flash dried by passage through a stream of air heated to 500 to 600°F. The dry solids are separated by passing through a cyclone. A new design for air-lift drying of potato granules feeds a mixture of freshly cooked potato with previously dried granules into the bottom of a drying column. Hot air enters this column through a jet and dries the material as it is conveyed upward through the main riser. Air velocity is reduced by means of an inverted truncated cone at the top of the drying column. The dry granules fall into an annular collector and are discharged through a cooling unit. The moist air is exhausted through a bag-type collector.

As illustrative of the application of dehydration to the manufacture of dried vegetables the procedure for producing dehydrated carrot pieces in tunnel dryers is as follows:

Fresh Carrots—suitable variety (Imperator and Chantenay) and maturity (6 to 7 months)

Harvesting—machine topped and dug or topped by hand twisting and pulled

Washing—removal of clinging soil

Peeling—steam peeler or lye peeler

Washing—remove adhering peel

Trimming—machine carrot cutter for butts and tops. Hand table trimming

Sizing—standard dicers which cut the carrot in three dimensions of various sizes

Blanching—5 to 6 min with live steam

Coating—spraying with a dilute solution of sodium bi- and sodium sulfite solution directly out of blancher or spraying with a 3 per cent boiling solution of "thin boiling" starch

Traying—1½ or less pounds per square foot of drying surface

Dehydrating—dry at 160°F with high-air velocity for approximately 5 hr on trays

Finishing—in bin at 140°F with low-air velocity for 4 to 5 hr to approximately 4 per cent moisture and 350 ppm of sulfur dioxide

Inspection and Packaging—dry inspect and pack in aluminum foil laminated on Kraft liner in fiberboard cartons or in 5-gal hermetically sealed tin can.

Controlling

Successful operation of any food process requires uniformity in the end result. Each unit of operation can be affected by changes in energy, in quantity and rate, and in various physical and chemical characteristics. It is essential to measure these changes and to control them in such a manner as to yield the desirable final product or effect. A control element, or system, provides a means of adjusting the range of a variable. It can be applied to insure the successful and consistent performance of a unit operation on food materials. Two examples are: (1) a valve to adjust the flow of steam to the interior of a drum-dryer, (2) a switch to start a belt conveyor to feed containers to a filling machine at a rate synchronized with the filling speed. When the range of a variable is controlled within predetermined limits, the system which accomplishes this is a regulation system.

Control methods may be either manual or automatic. A minimum of instruments for measuring certain variables is essential in guiding operators. Many food processing procedures are susceptible of partial or complete automatic control, in which case instrumentation is an absolute necessity. Every properly designed application will result in improved operation. The foremost result is the improvement of product quality and uniformity.

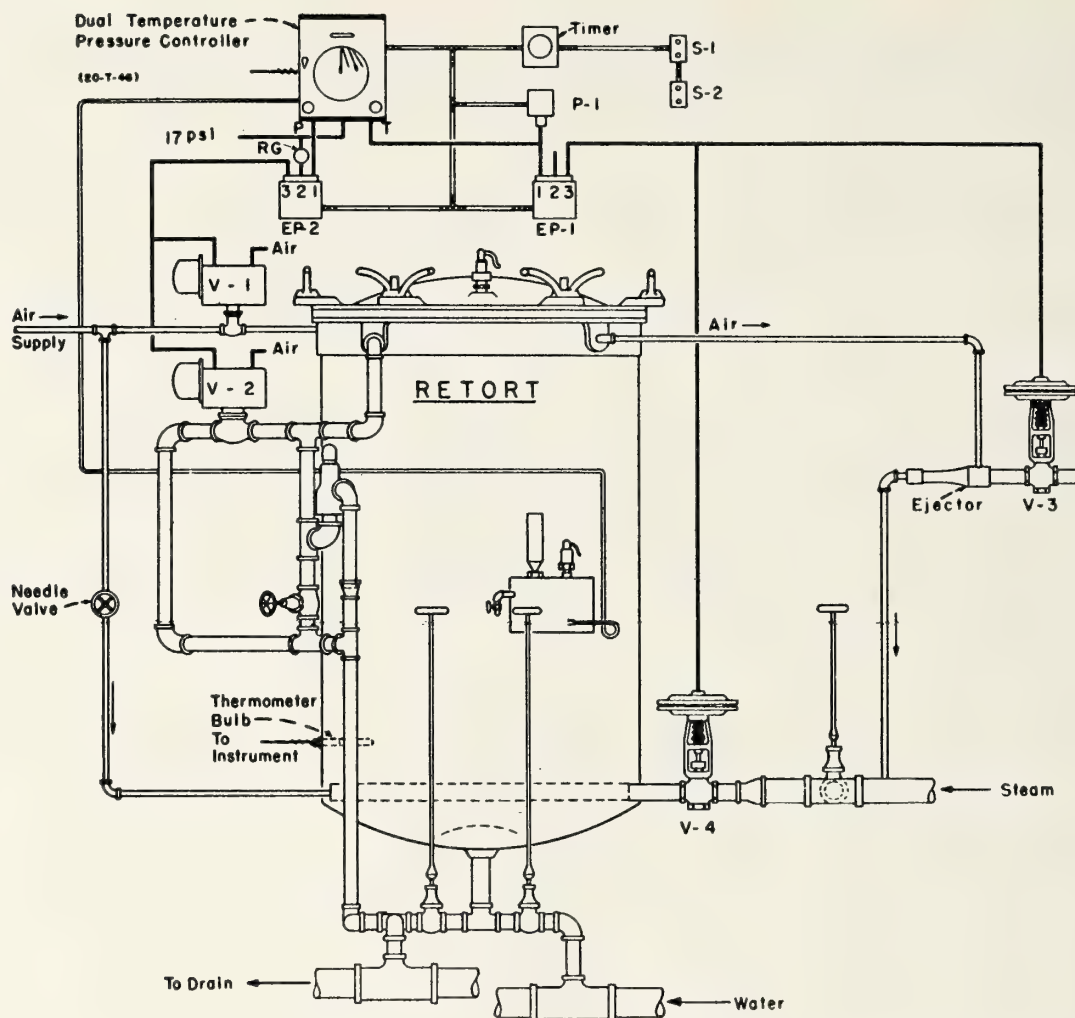
Quality control of food processes involves the effective application of accumulated knowledge and experience. The distinctive elements of importance in the acceptability of the food must be evaluated and controlled. Standards of performance which affect the quality of individual characteristics can be specified. Many of the variables involved such as time, temperature, rate of flow, etc., can be measured by a physical means which is susceptible of regulation. There are a number of qualities concerned with the acceptability of a food which must be evaluated subjectively. Such

characteristics as taste, mouth feel, chewiness, odor and appearance are determined by organoleptic methods in which the training and experience of the individual judge will affect his judgment of the closeness of approach to the desired standard.

In the final analysis, the control of a food process or unit operation is a problem of economics. The extent of instrumentation will be dictated by the essential contribution made to producing an acceptable product at a profit. The determination of the frequency and completeness of application of quality control which is justifiable has led to the application of statistics in the treatment of observed data. Since many of these are dependent upon subjective measurements, rather than physical means, the application of statistical quality control in the food industry is much more difficult than in chemical processing, where departures from the norm can be observed objectively with precision.

With natural systems, such as foods, two types of variables exist. There are indeterminate ones, which vary of their own accord, and determinate variables, which may be made to vary by suitable control elements. The types of measuring instruments which must be employed depend upon the variables under measurement, each of which may require an individual type of measuring means. Among the many elements requiring control are temperature, pressure, fluid flow, pH, specific gravity, viscosity, humidity, liquid level and time. In contrast, a wide range of instruments may be made to actuate controls at some particular point of variance, whether of time, or temperature, or other. The regulatory system is motivated only by a change or deviation of a process variable, and is therefore independent of the nature of the variable or the measuring instrument used. Controller devices may be made to control at a particular value of a variable, or according to a definite time schedule. They may control the duration of various operations, and even shut them down in case a dangerous or undesirable condition arises.

A process variable is any condition or state of the material or its environment that is subject to change. Certain ones will remain within suitable limits and do not need to be controlled. Some will be dependent on others, and do not require independent control. A third group are the independent variables which affect the result sufficiently to require control. The classification of process variables might be made from several points of view. A convenient basis is whether they are affected by (1) the energy state of the material, (2) the quantity or flow rate relationship, (3) the properties or characteristics of the material, or (4) time. In food processing, temperature, pressure and vacuum, and electricity are the most frequently occurring energy variables. Liquid flow, liquid level, weight and weight flow rate, thickness of solids and speed of machinery are quantity and weight vari-



(Courtesy Brown Instrument Co.)

Figure 21-13. Schematic diagram of three-way control system for water or steam cook with optional pressure cooling.

S-1. Electric switch, single pole single throw; S-2. Electric switch, single pole double throw; EP-1 and 2. Electric pneumatic relays, energized 1 to 3; V-1. Gradutrol valve controlling air pressure; V-2. Gradutrol valve controlling overflow; V-3. Diaphragm motor valve controlling steam admitted through air ejector; V-4. Diaphragm motor controlling steam admitted directly; P-1. Non-indicating pressure controller; RG. Air pressure regulator set at $7\frac{1}{2}$ pounds.

ables. Among the physical and chemical characteristics of importance may be included density and specific gravity, humidity, moisture content of solids, viscosity and consistency, color, refraction index, and hydrogen ion concentration.

A measuring instrument has a primary element to detect changes in the magnitude of the controlled variable, a transmitting means, and a measuring element. These devices may be classified as indicating, recording, controlling, or transmitting. Regardless of the measurement made, sensitivity and responsiveness of the primary element is absolutely essential. Since the response of the regulating system depends on the rapid and accurate detection of changes in the variable, no controller can be any better

than its measuring element. The mercury-in-glass thermometer is one of the most widely used instruments in food processing. Its cost is low; its accuracy is very good, and it is highly sensitive. Thermocouples have a limited use in the food industry. Pressure devices such as the glass manometer, the sight gauge glass, and the Bourdon tube are used to measure differences in pressure. Sealed-type diaphragm instruments or spring-opposed bellows elements find considerable application.

Any indicator must have a calibrated scale and a pointer to indicate the instantaneous value of the variable. The pointer may be attached by ligatures to the measuring element. Recording scales may be circular in form or the scales may be straight, as in a strip-chart instrument. Recording mechanisms make possible a permanent record of the changes in a variable with time.

Regulation may be manual or automatic. If the control of the variable within limits is secured by the direct action of a person, the system is of the manual type. In fully automatic regulation, suitable devices are provided which, by themselves, secure the desired regulation of the variable. The elements of a process system consist of an agent, which is a quantity to be controlled, an action, which is the manner in which the agent is utilized, and the effect, which is the change which acts upon the agent. The purpose of regulating is to limit the magnitude of changes in the variable. A system of regulation involves (1) a calibrated sensing device to detect and measure the magnitude of changes in the variable, (2) a device for operating the control element at a particular value of the variable (set-point element), (3) a control device actuated by the sensing and set-point elements and acting upon the agent. There is often a time lag between the change in the agent and the action produced. This may involve the addition of a cycling element to the regulation system to limit the degree of overshooting or under-shooting which occurs. It is also frequently necessary to employ an amplifying device, because the power produced by the sensing element is insufficient to operate the control element.

The control elements in a regulation system may be classified as (1) valves, (2) switches, (3) louvres, and (4) rheostats. Their physical form may vary considerably. The sensing element which measures the effect requires a control element which will respond to this effect; further, that the response be such that it can be utilized in a regulation system, that it be sufficiently sensitive, and that it be rapid in its response. The variety of sensing elements used is extremely wide and the combination of methods and instruments for effecting regulation are numberless. Automatic control of unit operations is much more limited in the food industry than in the chemical industry. Parts of a processing procedure are frequently controlled automatically, but full automatization is rare. The investment required in

equipment and regulatory systems is usually very substantial and its amortization may exceed savings in wages which automatization makes possible.

Packaging

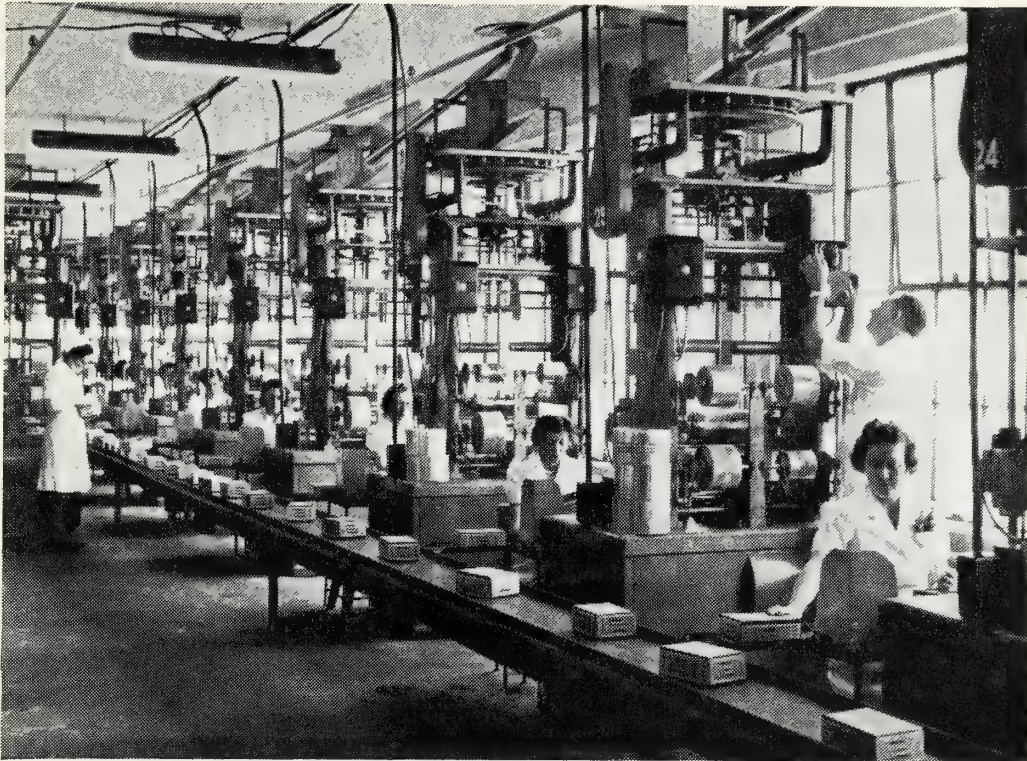
Packaging as a unit operation might be considered as an aspect of materials handling. Its function is to prepare a product for shipment. The importance and variety of packaging used in the food industry is such as to warrant its consideration as a separate operation. While bulk containers are used for packaging of food products shipped by the original handler, the term packaging is customarily restricted to the containers used in the retail or consumer sizes or units.

It is imperative that processed foods be properly packaged. The selection of the material, shape, and size is frequently dictated by considerations of convenience, economy and customer appeal. On the other hand, utilitarian motives often control. Canned foods must be hermetically sealed. Frozen foods have to be so packaged as to prevent deterioration, particularly dehydration, during storage. Dry food products must be protected against insect and rodent infestation, and, in the case of dehydrated foods, against moisture up-take. For certain food products exclusion of oxygen is highly important, in some instances requiring packaging in an inert gas atmosphere or vacuum, as with coffee or dry whole milk.

The most universally used packaging material is paper. Paper bags, cartons, envelopes, wrappings, boxes and even fiber cans require vast quantities of paper products. Combinations of paper with metal or plastic films are becoming of increasing importance. The metal end container with paper sides is adaptable for automatic filling and is finding increasingly wider use, particularly in the frozen food industry.

The metals commonly used for packaging are steel, aluminum, and tin. The so-called tin can is basically made from a steel sheet, electrolytically coated with a very thin layer of tin. Frequently coatings, often of plastics, are applied to the tin-coating to provide additional protection against special conditions. Such plastic or resin films are baked on to the tin-coated metal. Black-plate is a term applied to steel sheet treated in a certain manner to make it suitable for particular products. The most common identification of size of tin container is by dimensions, which specify the diameter and height of the can. For example, 303 x 407 identifies a can $3\frac{3}{16}$ in. in diameter by $4\frac{7}{16}$ in. in height. In some foreign countries aluminum cans have found considerable favor. In general, their higher cost operates to restrict their use.

The spectacular increase in the production of transparent plastic films since the end of World War II has led to very considerable application of



(Courtesy Stokes and Smith Co.)

Figure 21-14. Installation of Stokeswrap automatic packaging machines at Planters Nut & Chocolate Co., Suffolk, Virginia. Peanuts are being packed in cellophane bags, which are made, filled and sealed in one operation.

such packaging to food products. Cellophane, saran, vinyl, pliofilm, polyethylene and cellulose acetate and butyrate offer the advantages of visibility and product protection. It has been asserted that “everything from artichokes to zucchini, apricots to winesaps, almonds to walnuts” now profit from transparent packaging. The advantage to the packer lies in reduction in spoilage, waste and weight loss. For the distributor it means extended storage life without spoilage. Such packaging offers the retailer an extension of the products shelf life as well as sales stimulation due to eye appeal. Yet out of 36 billion pounds of fresh fruit and vegetables eaten in the United States in 1953 only about 4 billion pounds were packaged in transparent wraps.

The newer plastic films lend themselves to an infinite variety of laminated flexible wall structures when combined with thin aluminum sheet and paper. Extremely moisture-vapor resistant packages can result. The eye appeal of aluminum foil or under-printed cellulose acetate is a big asset in attracting impulse buying. Attractive packaging well displayed in self-service food stores causes purchasers to pick out unplanned items which may total 50 per cent of their entire purchase.

Glass containers are superior to metal cans for many foods because of the inertness of the wall material and the opportunity afforded the customer to inspect the contents of the container. It is interesting to note that

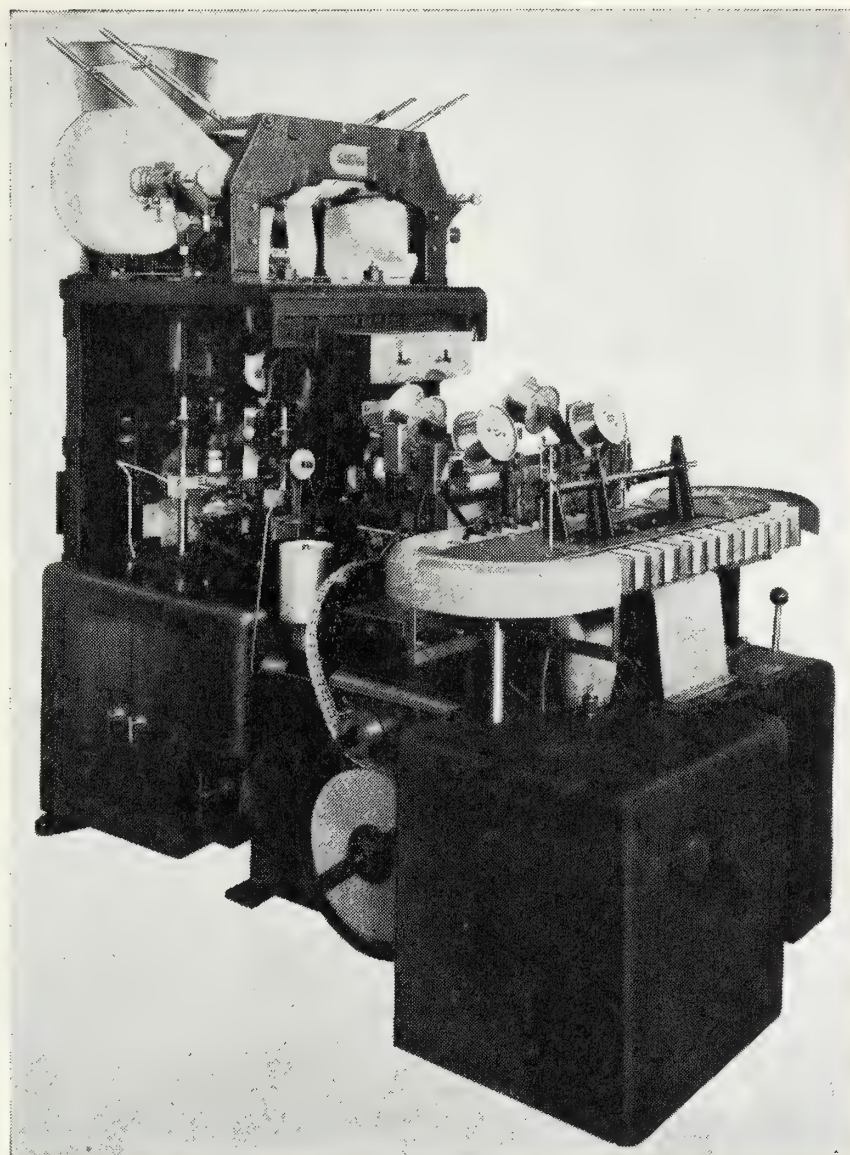
baby foods and junior foods were originally packed entirely in glass because of this eye-appeal. Today, probably as large a volume of such foods is packed in tin as in glass. The thermo-processing of foods in glass as well as in tins is included in the term "canning," as used today.

The selection of packaging equipment for food products will be determined by the physical characteristics of the product, the container selected for it, the maximum and minimum production rates planned, the lay-out of the plant, and whether the factory storage is in bulk or in containers. This requires the food engineer to consider each problem involved and make a judicious selection from the many types of packaging equipment available. So many applications are highly specialized that it is frequently difficult to obtain adequate information on the various possibilities.

Whether the food product is stored or handled in bulk, or in containers, prior to packaging, will depend upon such factors as the effect on the quality of the product, the layout of the plant, and the flow characteristics of the material. Considerable economies can be effected through bulk handling, but the cost of tanks or bins is considerable. Scaling may be automatic, but where the weight of dry food material to be delivered is small volumetric fill is preferable. Equipment for filling liquids is of the constant level, weighing, or metering types. The constant level fillers operate by pressure, gravity, vacuum, or a combination of vacuum and gravity. Metering fillers are usually actuated by piston pumps, and are employed for handling viscous liquids. Weighing fillers are usually hand-operated. They consist essentially of a scale beam that actually is a valve which cuts off when the scaled beam is tipped.

Bottle closures may be applied by hand-operated, semiautomatic or fully-automatic equipment. For bottling beverages cork-lined caps are positioned mechanically and are crimped on. Screw caps must be applied with sufficient force to form a light seal, with a flexible cap liner making contact around the lip of the bottle. Metal cans are closed by spinning the top on the filled can with a rotating seaming device for crimping the can body and the lid together. In filling dry products, equipment selected may depend on net weighing, gross weighing, or volumetric measure. The latter can be used only for products that can be maintained at a reasonably constant density. Automatic equipment is available which feeds collapsed cartons, forms them, seals the boxes, forms and inserts bag liners, and seals the top flap. The automatic cartoning of previously packed bottles or jars is used to some extent in the food industry.

In the wrapping of packages of food products, the edges of the wrapper may be secured by adhesive, or heat-sealing transparent overwraps can be automatically handled, even for irregularly shaped articles. In tight wrapping, the inside surface of the wrapping material is coated with adhesive



(Courtesy Pneumatic Seale Corp.)

Figure 21-15. Duplex Heat Seal Tea Bag Machine with Tag Unit Automatic Counter and Stacker.

and firmly attached to the plain chipboard carton. It is particularly good in protecting food against insect infestation. Tea is packaged in an automatic machine that forms a small bag, fills it with a volumetrically-delivered portion of tea leaves, seals it, and staples a string tag to the bag.

Labeling machines apply adhesive to the labels and then attach them to the container or apply adhesive to the container and then attach the label. Fully-automatic labeling equipment operates at high speed. Round cans usually have wrap-around labels, while irregularly shaped packs, particularly glass jars, are usually only partially covered by the label.

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22. FOOD PACKAGING

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In the merchandising of commodities, the practice of product packaging has become so extensive and the efficacy of the technics of package manufacture and of packaging practice has attained such importance, that packaging has come to be regarded as an industry within itself. Of all classes of commodities, foods probably present the greatest diversity of problems to the packaging technologist and engineer. This chapter will present a survey of these problems and of industry operations, with special emphasis on primary packaging.

Classification of Containers

Primary containers are the first containers into which a food is put. For the most part, they are the smaller sized containers, constituting both shelf sizes and institutional sizes; they may range in size from one ounce to one bushel capacity. For handling and storage, primary containers of a product are often packed in dozen, multiple dozen, or hundred-unit lots in secondary containers. These containers, most frequently, are made of fiberboard or wood, although some are made of plastic.

In this discussion, secondary containers will be mentioned occasionally but attention to them must be scanty because of the limitation of space. Since the protection or the preservation of the packaged food depends fundamentally upon the primary container, this container merits, and must receive, major attention.

There is a rough correlation between the amount of liquid constituents in packaged foods and the degree of rigidity of the containers used for the foods. Most foods having a high liquid content are packaged in rigid containers made of metal, glass, plastic, or paperboard. Highly viscous products, containing a comparatively low percentage of liquid constituents, are packaged predominantly in rigid containers, although an appreciable num-

ber are packaged in nonrigid containers made of metal foil, plastic film, or parchment or paper sheets. The majority of dry products is packaged in nonrigid containers. These products, if in solid state, may be in block form, in which case, the shape of the block determines the shape of the finished package; or they may be in either powdered or granular state, in which case, the products merely fill the containers, either rigid or nonrigid, of the size and shape provided.

From the standpoint of problems involved in the use of packages, the principal distinctions between rigid and nonrigid containers lie in (1) storage of the empty containers and (2) character of filling and sealing machinery required. These distinctions will be discussed later.

A container which permits no gas or vapor to pass through its seams, its top, its bottom, or its walls is a hermetic container. Containers of some types, ordinarily considered to be hermetic, do not meet the requirements of this definition. Sometimes, a seam of a container functions as a filter, permitting gas to pass through but purifying the gas during its passage so that no solid entities, even those as small as microorganisms, pass through with the gas. This condition exists when a paper gasket is used in a rolled seam of a metal container unless the pores of the paper have been filled with a substance that is nonpermeable to gas. It exists also when certain types of rubber gaskets are used on glass containers.

The supreme test of a hermetic container comes when there is a substantial pressure differential between the interior and the exterior of the container. Such a pressure differential tends to force gas through any permeable material which separates the inside gas from the outside gas.

No nonrigid container for food is classed as a practical hermetic container because no material, ordinarily considered as flexible material, except thin sheet metal, is absolutely impermeable to gas. No way, except soldering, is known to produce a reliable hermetic seam in flexible metal and, even when such a seam is produced, flexing of the metal in use is likely to produce perforations.

It is desirable that a rigid container be capable of retaining its shape, in its essential characteristics, under the stress of either internal vacuum or internal pressure. Practically all sterilized foods are held under vacuum, as are also some nonsterile dry foods, such as coffee. Sometimes, air is replaced by an inert gas, of which the most commonly used is nitrogen. This practice most often occurs with powdered products, for example, dry whole milk, in which protection from the effects of oxygen is desired and for which a container is used that lacks the mechanical strength necessary to withstand the physical stress of vacuum. Some primary food containers are specially constructed to make them capable of withstanding internal pressure exceeding atmospheric pressure by from one to five atmospheres. These containers are

used for such products as carbonated beverages and the "whipped-cream" type of products.

Foods that have liqueform characteristics contain either water or edible oil in considerable quantity. They may be called moist foods. Moist food products are perishable from action by microorganisms, from action by enzymes, and from action of chemical nature not associated with microorganisms or enzymes. Because of their liqueform nature, these foods are packaged in materials that are either moisture proof, oil proof, or highly resistant to penetration by water or oil. Metal, glass, plastic, or fiber, coated with either wax or synthetic plastic, are commonly used for containers of moist foods. Because of their perishable nature, these foods are packaged in hermetically sealed containers if they are to be held for a substantial length of time; if the required holding period is so short that spoilage can be prevented even though the causative agents are in contact with the food, non-hermetic containers are used.

Foods that contain insufficient water or oil to give them a moist appearance are dry products. From a packaging standpoint, the category of dry products embraces particulate products which behave as dry products behave in all respects except that, within the particles, they are moist and subject to spoilage like moist products. Examples are fresh fruits and vegetables protected by skins. These, as well as products which are dry throughout, such as cereal products are packaged in baskets, boxes, and bags; the bags are made of fabric, paper, or plastic.

History and Statistics

The first man-made containers for food, composed of either wood or stone, served the purpose for dry food products, such as cereals, as well as any open top containers used today. To wet products, these containers offered no protection against spoilage inducing factors, such as microorganisms and oxygen. A primitive means of supplying some protection from microorganisms was with the use of a layer of fat or of wax, which still serves as a domestic expedient. Bladders and parchment paper, either as containers or covers of containers, represented a bit of progress in providing protection for food; however, only when containers were produced which were capable of being cooked could it be said that progress worthy of the name had been achieved toward protection of food from the action of spoilage producing elements.

A tight closure on a food container, however, while essential for accomplishing the preservation of food, which is susceptible to spoilage by microorganisms, is of practically no value unless its use is accompanied by processing of the food to destroy viable microorganisms present therein—the process which resulted from the work of the brilliant French scientist, Nico-

las Francois Appert, at the advent of the 19th century. Appert invented the process of sterilization of food by heat. He found the problem of producing a hermetic seal with the bottles and corks that were available to him to be a momentous one. Bitting¹ abstracted Appert's description of his work with containers, as follows: "Bottles were used as they were 'most impermeable to air,' but as the ordinary ones had openings too small and were otherwise too weak to resist the treatment in corking and heating, he had special bottles made, some having openings of more than four inches. He made the stoppers from 3, 4, and 5 layers of selected cork with the pores running horizontally so as to hinder access of air."

A demonstration of his method in England by Appert in 1814 led to the designing of tin containers by the English. Later Appert used tin cans in his business, manufacturing them in his own factory because he could not get them made satisfactorily elsewhere. He formed the cans of wrought iron, presumably by drawing, then tin plated them. He made round, oval, and rectangular cans—the latter in order to conserve space aboard ship. Because of the extra care and expense involved in both making and closing rectangular cans, however, Appert discouraged their use.

The first English patent on preserving food "in bottles or other vessels of glass, pottery, tin, or other metals or fit materials" was issued to Peter Durand in 1810.

In 1824, Appert demonstrated that he had successfully preserved beef in containers holding more than 10 kg each and he received a reward for having done this. One of his containers held 17 kg.

The use of tin cans of increased physical strength facilitated heat sterilization procedures at temperatures above 212°F. Such procedures entered a period of more rapid development than previously; using autoclaves, salt baths, and retorts. The advent of the tin can has been called⁶ the first great stride in the food preservation business, as it opened a large field for work in the preservation of meat, vegetables, and fish.

It is believed that commercial food preservation in glass jars was begun in United States by Wm. Underwood in Boston, Mass., in 1821. On January 19, 1825, a United States patent was issued to Thomas Kensett and Ezra Daggett on a process for preserving food in "canisters of tin." By 1840, it is said that glass jars had been largely displaced in commercial canning by the metal container because the problems involved in sterilizing and handling tin cans were less numerous and less complex than those associated with glass containers.

The use of metal containers increased rapidly in Europe and the United States during the latter half of the 19th century. All seams of tin plate cans were soldered. The bottom end of the cans, when made as a separate piece and attached to the wall, or body, of the can, was itself a shallow container,

hand-formed in the early styles and mechanically drawn in the later cans. The wall of this shallow container, which constituted the bottom end of the can, was from $\frac{1}{8}$ to $\frac{1}{4}$ inch high, perpendicular to the plane of the bottom, and of the proper outline to make it fit closely to the outside surface of the wall of the can. Solder was sweated onto the overlap surface of the can wall and the wall, or, as it is sometimes called, the flange or the skirt of the bottom end. The top end was soldered to the wall of the can in the same manner as the bottom. This also was part of the operation of manufacturing the can. The top end had a round hole in the center, varying in diameter from $\frac{3}{32}$ to about $2\frac{3}{4}$ inches. The can was filled through this hole, which was then closed and sealed with a disc (cap) and solder, or, in the case of the smallest hole, with solder alone.

Sanitary Cans

Since the advent of the 20th century, the soldered seam cans, called hole-and-cap cans, have been replaced for heat sterilized foods by cans with rolled seam ends, called sanitary cans; except in the evaporated milk industry, where, because of lower cost, soldered seam cans are still used. With the use of a new technic for attaching the ends to cans came a rapid increase in the rate at which cans could be manufactured and in the rate at which they could be filled and sealed. Today, a single machine manufactures food cans of shelf size at the rate of 450 cans per minute and cans of the smaller shelf sizes are filled and sealed in a single production line at rates that "push" 800 per minute.

These developments brought a reduction of cost of canned foods, which, together with product quality improvement through the application of scientific methods in the production of raw materials and packing operations, has brought a vast increase in per capita consumption of such foods. Against a consumption in the United States of 1,500 million cans, or about 20 cans per person in 1900, the consumption has risen to 23 billion, or about 145 cans per person today. More than half of that increase has taken place since 1935.

Not all of these cans are used for foods which, in the conventional sense, are known as canned foods, that is, foods that are processed for sterilization. In recent years, larger and larger quantities of frozen foods are being packed in cans; most prominent among these are fruit concentrates. Dry products, such as coffee, powdered milk and pop-corn, also utilize a considerable number of cans. These products are packed in hermetically sealed containers because the preservation of quality in these foods depends on maintaining control of the composition of the atmosphere surrounding the products during storage.

A comparatively small percentage of the frozen foods, particularly of

TABLE 22-1. VOLUME OF PRODUCTION OF CANNED AND FROZEN VEGETABLES AND FRUITS (Farm Weight Equivalent Basis)
Vegetables and Vegetable Juices

Year	Total		Frozen		Canned		Canned as per cent of total	
	All containers	Retail containers	All containers	Retail containers	All containers	Retail containers	All containers	Retail containers
	<i>million pounds</i>		<i>million pounds</i>		<i>million pounds</i>			
1946	7,740.0		450.0		7,290.0		94.2	
1947	6,937.2		346.2		6,591.0		95.0	
1948	5,996.4	4,945.1	446.4	284.5	5,550.0	4,660.6	92.6	94.2
1949	5,924.5	4,760.6	563.5	363.6	5,361.0	4,397.0	90.5	92.4
1950	6,341.1	5,231.7	587.1	389.6	5,754.0	4,842.1	90.7	92.6
1951	8,096.0	6,404.2	770.0	527.4	7,326.0	5,876.8	90.5	91.8
1952	7,712.9	6,168.1	895.7	595.0	6,817.1	5,573.1	88.4	90.4
Ave. '48-'52 . . .	6,814.2	5,501.9	652.5	432.0	6,163.6	5,069.9	90.5	92.1

Fruits and Noncitrus Fruit Juices

1946	5,059.3		523.3		4,536.0		89.7	
1947	4,140.8		347.3		3,793.5		91.6	
1948	4,130.7	3,317.7	377.7	74.3	3,753.0	3,243.4	90.9	97.8
1949	4,417.5	3,475.1	354.0	72.8	4,063.5	3,402.3	92.0	97.9
1950	4,778.7	3,623.4	472.2	96.5	4,306.5	3,526.9	90.1	97.3
1951	4,857.4	3,718.8	415.9	90.2	4,441.5	3,628.6	91.4	97.6
1952	4,951.3	3,925.6	420.3	126.0	4,531.0	3,799.8	91.5	96.8
Ave. '48-'52 . . .	4,627.1	3,612.1	408.0	91.6	4,219.1	3,520.2	91.2	97.5

NCA Information Letters, Sept. 19 and 26, 1953.

the noncitrus fruits, is put into containers suited for retail distribution and, of that part which is sold at retail, except for citrus concentrates, by far the greatest portion is packed in fiber cartons, mostly folding boxes. The volume of production of canned and frozen vegetables and fruits, excluding citrus, broken down into categories of "all containers" and "retail containers," for the five-year period, 1948-1952, is displayed in Table 22-1. Also shown are the total volumes for the years 1946 and 1947 and the percentages which the volume of canned foods represents of the totals. A further indication of the rate of increase in the volume of frozen vegetables is given by the fact that, in 1942, the first year of World War II, 162 million pounds were produced in the United States.

TABLE 22-2. INDUSTRY CITRUS CAN SHIPMENTS

Year	Frozen citrus concentrate (6-oz. cans)			
	Millions cans	Pounds product	Millions cans*	Pounds product*
1947	11.9	4,460,000	11.9	4,460,000
1948	50.1	18,750,000	50.1	18,750,000
1949	273.6	102,400,000	265.0	99,300,000
1950	636.0	238,000,000	597.8	223,500,000
1951	832.3	311,300,000	754.7	282,100,000
1952	1,182.7	443,000,000	1,053.3	394,500,000
1953	1,322.4	496,200,000	1,112.5	416,800,000

Statistics by American Can Company.
* Excluding lemon products.

The phenomenal expansion in the use of cans for frozen citrus concentrate makes it desirable to present statistics on those cans separately from other frozen foods containers. Use of these cans in the United States during the period 1947 to 1953 is given in Table 22-2. The numbers given are slightly larger than the actual numbers of 6-ounce cans used because the figures represent the quantity of material packed and not the number of cans used. Since a small part of the frozen citrus concentrate is marketed in larger than 6-ounce cans, the actual numbers of cans used are slightly smaller than the numbers given. Table 22-2 reveals that, starting in 1949, the packaging of frozen lemon concentrate has expanded during four years at a rate which is approximately 28 per cent of the rate of increase in the volume of frozen citrus products other than lemon during the period 1947 to 1951. In 1953, more than 200 million cans were used for frozen lemon products.

Including frozen citrus products, the distribution of cans, by percentages of steel used, among the different categories of foods in the years 1950, 1951 and 1952 is shown in Table 22-3.

Carbonated beverage constitute the remaining food item for which a large number of cans is used. The year 1935 marked the first substantial use of cans for beer. At the outbreak of World War II, cans were being filled with beer at the rate of 2 billion per year. After a serious setback during the war because of shortages of steel and tin, the prewar scale of use was again attained in 1947. The numbers of 12-ounce cans filled with beer in the years 1947 through 1953 are shown in Table 22-4.

In 1952, carbonated soft drinks were first marketed in cans in more than an experiment way. The estimated consumption in 1953 was 130 million cans and the trend toward cans seems to be so accelerated that some estimates place the expected use of cans for soft drinks in 1954 to exceed that of 1953 by 400 to 500 per cent. For a number of years, paper container

TABLE 22-3. END USE OF METAL FOOD CANS IN 1950-1952

Product type	Percentage on basis of steel used		
	1950	1951	1952
Fruits and vegetables.....	41.3	43.8	42.2
Evaporated milk*.....	8.0	8.1	7.9
Condensed milk.....	0.2	0.19	0.16
Other dairy products.....	1.1	1.11	1.04
Fish and sea food.....	4.7	3.4	3.4
Pet foods.....	3.7	3.3	3.9
Lard and shortening.....	3.2	2.7	3.0
Other foods (including meat, beer, and coffee)	37.8	37.4	38.4
Totals.....	100.0	100.0	100.0
Short tons of steel used.....	3,159,198	3,091,460	3,171,056

(One short ton equals 23.0 base boxes of steel: approximately 8,850 #2 cans are produced from one ton of steel of 85 pounds base box weight.)

* Practically all evaporated milk cans have soldered end seams.

TABLE 22-4. INDUSTRY BEER CAN SHIPMENTS

Year	Millions 12-oz. cans
1947	2,151
1948	2,900
1949	3,690
1950	5,118
1951	4,520
1952	5,023
1953	6,308

Statistics by American Can Company.

makers have been trying to perfect a paper container for soda pop and spokesmen for the manufacturers say that when this task is mastered, the industry will “have a look at the beer market.” If this purpose is accomplished, in view of the momentous problem involved in adapting a paper container to soft carbonated drinks, the paper container industry will richly deserve to “have a look” at numerous fields in which it is not currently active.

Other food products requiring cans capable of holding pressure of at least 100 psi gauge are now being packed at the rate of about 50 million cans per year—mostly cans of a 12-ounce capacity. These products are largely dairy product formulations containing cream, packed with a soluble gas, such as nitrous oxide, under pressure. They are discharged from the cans as whipped cream or a simulated whipped cream through a pressure-tight valve. The number of cans used for products of this type is increasing at a high rate.

Glass Containers

The use of glass containers expanded in volume greatly during World War II, when, because of shortages of metals, they were used for many food products for which metal containers are customarily preferred. With the end of restrictions on the use of metals, a decline in the volume of packers' glassware began in 1947 and continued through 1949, after which the number of glass containers used for all types of food began an upward trend which continued through 1953, during which year the peak volume of World War II was exceeded.

The number of glass containers used for food, including soft drinks and beer, during the period 1946 to 1953, is shown in Table 22-5. The upward trend for the period 1949 to 1953 continued into 1954. A breakdown, by percentages, according to specific end use, of the containers listed in Table 22-5 under the category of "packers ware" is given in Table 22-6 for the period 1946 to 1949. The classes of containers in Table 22-6 that show a distinct declining trend with time are those which tended to pass from glass to metal containers after 1946. Those which experienced a sharp increase in volume in 1947 over that of 1946 and thereafter passed through either a steady or a decreasing trend are for the types of foods for which the use of containers was drastically restricted during the war. A line of products with which glass containers have an out-standing record since World War II is baby foods. That record is shown in Table 22-7 for the period 1946 to 1953. The volume of glass containers used for baby food during that period increased by about 100 per cent. The increase was continuous even between 1946 and 1949, when the general trend of glass container use was down.

Paper Containers

Of even greater importance as food containers than metal cans and glass containers are folding boxes and paper milk containers. To complete the statistics on container volume, Table 22-8 gives the estimated production of all consumer containers for 1940 and 1950 to 1952. A large percentage of all types listed, except collapsible tubes and plastic bottles, is used for foods. Paper, particularly paperboard, is used so extensively in the retail packaging of commodities that the volume of paper business is considered by many to be a reliable gauge of the condition of business in general.

According to the best available information, 36 per cent of folding boxes is used for food—many of these, of course, for frozen foods. Approximately 1 per cent of folding boxes is used for beverages—as secondary containers. Production of paper was approximately 9 per cent greater and production of paperboard approximately 7 per cent greater in 1953 than in 1952. Although it is expected that production volume of these items will be less in

TABLE 22-5. INDUSTRY GLASS CONTAINER DOMESTIC SHIPMENTS FOR FOOD
(Thousands of Gross)

	1946	1947	1948	1949	1950	1951	1952	1953
Wide Mouth								
Packers ware.....	45,155*	36,771*	34,178*	23,332	29,775†	28,331†	30,774†	33,677†
Dairy.....	3,897	3,891	3,247	3,311	3,695	3,517	3,150	3,363
Home canning.....	2,593	2,175	2,117	1,763	—	—	—	—
All wide mouth.....	51,645	42,837	39,542	28,406	33,470	31,848	33,924	37,040
Narrow Neck								
Packers ware.....	—	—	—	8,835	11,061	11,528	11,918	12,543
Beverage, returnable.....	6,456	10,377	7,805	5,274	6,291	6,398	7,898	8,787
Beverage, nonreturnable.....	—	—	—	51	168	180	447	1,056
Beer, returnable.....	5,904	9,952	4,100	1,995	3,155	4,524	2,258	2,854
Beer, nonreturnable.....	878	3,039	3,565	3,001	3,211	9,816	8,198	8,331
All narrow neck.....	13,238	23,368	15,470	19,156	23,886	32,446	30,719	33,571
Totals.....	64,883	66,205	55,012	47,562	57,356	64,294	64,643	70,611

Based upon statistics of Glass Container Manufacturers Institute.

* Includes narrow mouth packers ware.

† Includes home canning ware.

TABLE 22-6. END USE OF PACKERS GLASS FOOD CONTAINERS IN 1946-1949

Product type	Percentage on basis of number of containers used			
	1946	1947	1948	1949
Baked beans	5.91	1.55	1.70	1.82
Catsup, chili and tomato juice	5.99	9.95	7.95	5.21
Other vegetables and vegetable juices	1.66	1.81	2.20	2.69
Cherries, maraschino . . . . .	.53	.63	.88	1.20
Fruit juices	1.76	2.27	2.44	2.34
Fruits	1.48	.95	.74	.92
Baby foods	9.89	12.40	17.51	16.93
Meats and fish products	1.51	2.36	2.04	1.55
Salad dressings, mayonnaise, and edible oils	9.46	13.20	14.92	16.64
Pickles and relishes	5.91	12.40	12.92	12.95
Olives	1.63	1.46	1.37	1.47
Preserves, jams, jellies, and fruit butter	9.70	13.82	13.17	11.67
Peanut butter	5.53	3.04	3.27	3.58
Sirups	13.88	8.62	8.77	9.57
Honey	1.66	2.15	2.09	2.47
Flavoring extracts	*	.72	.74	.73
Spices and seasoning . . . . .	.30	.34	.33	.30
Mustard	1.84	2.44	2.42	2.34
Horse radish . . . . .	.22	.26	.25	.22
Sauces and meat gravy	1.28	.63	.74	.73
Vinegar	2.38	1.81	1.95	2.06
Miscellaneous	17.48	7.19	1.60	2.61
	100.00	100.00	100.00	100.00

Based on Statistics of Glass Container Manufacturers Institute.

* Included in miscellaneous.

1954 than in 1953 (however, still greater than in 1952), it is nevertheless expected that the volume of paper and paperboard used for food containers in 1954 will exceed that of 1953.

The percentage of glass containers which is used for food is apparent by comparing Table 22-5 with Table 22-8. For metal cans, the number of short tons of steel used for food was 2,559 thousand in 1951 and 2,555 thousand in 1952.

TABLE 22-7. INDUSTRY GLASS CONTAINER DOMESTIC SHIPMENTS FOR BABY FOOD

Year	Number (thousands of gross)	Total number of packers ware containers shipped	% of total packers ware
1946	4,462	45,155	9.89
1947	4,556	36,771	12.40
1948	5,992	34,178	17.51
1949	5,450	32,167	16.93
1950	6,471	40,836	15.84
1951	6,035	39,859	15.11
1952	6,822	42,692	15.97
1953	8,104	46,220	17.52

TABLE 22-8. ESTIMATED PRODUCTION OF RETAIL CONTAINERS, 1940 AND 1950-1952

Type of container	1940	1950	1951	1952
Metal cans (1,000 tons of steel).....	2,192	3,893	3,805	3,842
Metal crowns (1,000 gross).....	143,929	344,196	330,785	337,584
Metal closures, commercial (million units).....	5,677	11,638	11,449	10,470
Plastic closures (million units).....	—	2,554	2,761	2,164
Glass containers (1,000 gross).....	52,116	106,380	117,692	115,631
Collapsible tubes (1,000 gross).....	3,755	6,792	6,390	5,956
Paper milk bottles (stock in tons)....	n. a.	219,920	259,062	301,126
Hood and lid covers (stock in tons)..	n. a.	26,871	36,057	21,933
Milk bottle plugs (stock in tons)....	n. a.	18,197	19,276	19,696
Liquid-tight containers (stock in tons)	n. a.	47,308	56,643	66,539
Cups, round nested containers (stock in tons).....	n. a.	106,219	129,029	112,848
Ice cream, frozen food, butter cartons (stock in tons).....	n. a.	189,389	200,865	190,671
Folding boxes (1,000 tons).....	1,398	2,356	2,362	2,193
Set-up boxes (1,000 tons).....	613	709	733	688
Fiber cans, tubes, and drums (1,000 tons).....	n. a.	315	326	300
Bag paper, including grocery and variety (1,000 tons).....	606	670	845	804
Aluminum foil, incl. foil in lamina- tions (1,000 lb).....	n. a.	106,700	110,900	90,500
Plastic bottles (million units).....	—	100	95	130

“Modern Packaging Encyclopedia,” 1954.

Shipping Containers

Removing our attention briefly from retail containers, in Table 22-9 is given the estimated production of shipping containers for 1940 and 1950 to 1952. A substantial number of steel drums and pails is used for food. An inspection of Tables 22-8 and 22-9 reveals a phenomenal increase in the use of fiber for packaging during the decade 1940-1950. For retail packages, paper has kept pace with metal and glass in accounting for increased volume during the 12 year period 1940-1952 and, for shipping containers, losses in

TABLE 22-9. ESTIMATED PRODUCTION OF SHIPPING CONTAINERS, 1940 AND 1950-1952

Type of container	1940	1950	1951	1952
Steel drums and pails (1,000 tons steel)	572	925	1,246	878
Nailed wooden boxes (million bd ft) ..	4,295	5,000	5,000	4,900
Wire-bound boxes (1,000 units)	78,175	158,087	176,062	190,000
Slack cooperage (1,000 units)	35,000	23,370	23,000	23,000
Tight cooperage (1,000 units)	9,675	4,472	3,300	1,800
Metal strapping (1,000 tons of steel) ..	100	350	425	300
Corrugated and solid-fiber containers (1,000 tons of stock)	3,114	5,830	6,323	5,766
Fiber drums (1,000 units)	3,500	26,000	25,300	24,000
Shipping sack paper (1,000 units)	195	748	849	753
Textile bags (million yd.)	1,538	1,158	1,075	1,131

"Modern Packaging Encyclopedia," 1954.

volume by textile bags and cooperage were far exceeded by gains by wire-bound boxes and fiber containers, including multiwall bags.

Requirements of a Container

The qualities of a container must be carefully evaluated during the process of developing or selecting a container for a specific use. The diversity of these qualities is at a maximum in consumer containers because every retail primary container is in contact with the product on its inside surfaces and must meet exacting requirements in this as well as in many other respects. A detailed description of the problems involved in producing all types of food containers, even if confined to retail containers, is beyond the possibilities of a discussion of the length of this chapter. The following pages, therefore, will be devoted to a treatment of retail containers from a functional standpoint, based upon an example of a proposed analysis of a specific type of container for appraisal purposes leading to a container development project. The type of container chosen for this example is the paper milk container; however, as each functional characteristic enters into consideration, analogous problems pertaining to this characteristic in various types of containers will be treated.

As a foundation on which to base an appraisal of a type of container, two series of factors will be used; the first series will be designated as basic factors and the second series, consumer acceptance factors. They are as follows:

Basic Factors

1. Price to packager
2. Sanitary qualities (protection of product from contamination)
3. Resistance to impact injury
4. Efficacy of interior surface

5. Absence of handling problems
6. Space and other storage requirements in filling plant and in distribution, including weight of package
7. Special features related to performance for packager

Consumer Acceptance Factors

1. Size
2. Ease of opening
3. Reseal features
4. Pouring qualities
5. Space saving in consumer's premises
6. Light protection
7. Transparency
8. Tamperproofness
9. Protection of contents from physical or chemical change
10. Physical characteristics of outside surface, including appearance
11. Ease of disposal
12. Special features related to performance for consumer

Some of these factors are not used in appraising certain types of containers. The reseal factor, for example, is ignored in appraising containers which are never to be stored after opening, containing a portion of the original contents. For some types of container, for example, a paper milk container, all of the listed factors may be needed in an appraisal.

Rating the Container

A procedure for rating the container on a numerical basis, in respect to each factor, must be evolved. The first step is to weigh the factors numerically in respect to each other; the second step is to evolve a procedure, including a mathematical formula, for computing the rating of a container in respect to each factor. These steps are to be taken with extreme care and deliberation by a panel or committee composed of specialists in technology, engineering, manufacturing, selling, and purchasing.

Weighted Values of Factors

After a complete discussion, the weighted value for each factor should be established by a majority vote of the committee. If the elements involved are thoroughly discussed, so that differences of opinion are effectually clarified, these decisions will usually be unanimous.

Evaluating the functional quality factors in this manner prevents the placing of unjustified emphasis on a particular factor which, when viewed in an isolated position, may appear to be endowed with great importance but which, when weighed carefully in relation to other factors, is of

5. (a) extra machinery required (over and above that required for the type of container in present use)
- (b) utilization of present filling equipment
- (c) filling speed
6. transportation to dairy may or may not be included
- Consumer factor 4. includes facility for separating cream from milk
9. includes cream absorption and adsorption

Principles of Grading

For successful operation of this system of grading, an explicit pattern must be designed by the committee for each factor and set forth in writing so that there is complete understanding by the committee members of all principles and tenets laid down in the pattern. In these expositions, not only the effects of various features upon the grades must be given but, also, the reasons why these effects are attributed to the particular features. Hypothetical patterns of grading principles for two basic factors and one consumer acceptance factor, applying to paper milk containers, will illustrate the type of grading pattern which seems best to serve the purpose.

Basic Factor No. 1—Price.

1. Price includes only cost (material, labor, overhead) plus $7\frac{1}{2}$ per cent profit before taxes—no transportation or jobbing cost.
2. Price of \$10.00 per M containers is given an ideal rating of 30 points.
3. Rating is calculated by equation (1)

$$N = 30 - 3(x - 10) \quad (1)$$

in which N is the factor rating of the container and x is the price per M containers.

Basic Factor No. 4—Interior Coating.

1. Ideal equals 10. Ten points to be divided evenly between (a) and (b) (see page 705); all paraffin coated containers rated 5 under subdivision (a).
2. Three-ply type end is considered least likely to produce flaking and is rated 4 under subdivision (b).
3. Type C end decreases rating from that of 3-ply end by $\frac{1}{2}$ point because of increased likelihood of formation of fillets.
4. Folding of types D and E tops after paraffining and less rigidity of these tops counterbalance the better paraffin drainage of these containers and the more numerous places for fillets in the type C end. The result is equal rating for types D and E. (Because of less rigidity during service, types D and E tops decrease the rating from that of the 3-ply top by 2 points and from that of the type C top by $1\frac{1}{2}$ points.)
5. Type F top has same rating as type D top.
6. Type G end decreases the rating from that of type C end by $\frac{1}{2}$ point because of lower rigidity of type G end. (One point lower than 3-ply end.)

7. Type F bottom has same rating as type G bottom. (One point lower than the 3-ply bottom.)

8. Use of type H top, with bottom filling, decreases rating by $\frac{1}{2}$ point from that of type C top and bottom because of increased danger of sluffing of paraffin in opening the bottom for filling.

9. Low coefficient of rigidity, increased area of folded top, and sewing of top causes reduction in rating by 2 points of type I container compared to type D.

10. Type J top decreases rating by 3 points from that of 3-ply top because of reduced rigidity and large number of places for fillet formation in type J top.

11. Cream baffle in container $8\frac{1}{4}$ " high decreases rating by $\frac{1}{2}$ point and in container 6" high by 1 point because of increase in opportunity for formation of fillets.

12. Body 6" high decreases rating by 1 point from that of body $8\frac{1}{4}$ " high because of greater opportunity for formation of fillets around top and bottom.

13. Cylindrical body is considered equal to rectangular body with ends of type C; $\frac{1}{2}$ point better than rectangular body with ends of type F or G.

14. Type K top has a rating 3 points lower than the 3-ply top because of the forming operation on the neck in closing.

Consumer Acceptance Factor No. 4—Pouring Qualities.

1. Ideal equals 3.

2. All containers except type I, type L, and short cylinder are rated 2.

3. Type L with round opening, short cylinder with opening near periphery of end, and type I are rated $1\frac{1}{2}$; type L with extended opening is rated 2; short cylinder with opening in center of end is rated $\frac{1}{2}$.

Note on above patterns: Types C to L, inclusive, designate particular designs, all of which are familiar to the committee members. These types figure in the grading patterns of other factors in a similar manner to that of their use in the patterns illustrated above. All combinations of features are thus graded under all factors. The ratings for each combination, representing a specific container design, under the factors of both series, are added to produce a composite rating for the container. The container receiving the highest rating is judged to be the best for the purpose.

Discussion of Grading Factors, Applied to Different Types of Containers

Basic Factor No. 1—Price to Packager. This is the one grading factor in the consideration of which the purchasing department of the container manufacturing firm plays an active part. This department must supply information on the availability and the price of materials. It may also assist the technical department in determining whether or not a material is a

suitable one for the container by obtaining certain items of technical information from the supplier.

Information collected by the purchasing department is combined with facts developed by the technical department and the manufacturing department on the manufacturing operations necessary; the accounting department then determines the cost of material, labor, and overhead, then the evaluating committee adds such percentage as has been decided upon as a proper mark-up to obtain the price, excluding storage and transportation on the finished container and jobbing cost. The committee then applies its price factor formula and obtains the price factor rating for the container.

It may be well to enumerate here a few principles on the relative costs of packages in different functional classifications. Generally, a container of type A in the following list costs more than a container of type B of similar size in the same line.

<i>Type A</i>	<i>Type B</i>
hermetic	nonhermetic
rigid	nonrigid
vacuum holding for moist products	pressure holding for dry products

Basic Factor No. 2—Sanitary Qualities. This factor is concerned with the protection afforded by the container to the contents against microorganisms and against filth. Any container which, in storage, affords protection from microorganisms protects also from filth; the reverse of this statement, however, is not necessarily true. It is an easier and a simpler matter to protect from filth than to protect from microorganisms. The latter type of protection is required for a product containing more than about 20 per cent of water, which is not protected by sufficient salt, sugar, acid, or alkali to prevent bacterial growth, and which must be held in the container longer than the normal spoilage time for the product at its storage temperature. Sterilized canned foods, of course, are the outstanding example of foods in this category. Hermetic containers are necessary to afford this protection. Figure 22-1 shows how this sanitary metal can is sealed hermetically and Figures 22-2 and 22-3 illustrate the means of sealing the commonly used types of glass containers.

Foods sold at retail that do not have to be hermetically packaged are predominantly packaged in tightly closed paper bags, folding boxes, film pouches, pouches of various laminates, molded plastic containers, or nonhermetic metal or glass containers. A container of any of these types, as long as it is unbroken and unopened, effectively protects its contents from filth. Among foods in this category are some which are subject to bacterial spoilage but of which the distribution is so controlled that spoilage does not normally take place. Such products are salad dressings, meat, fresh and cured, and fresh dairy products, including fluid milk.

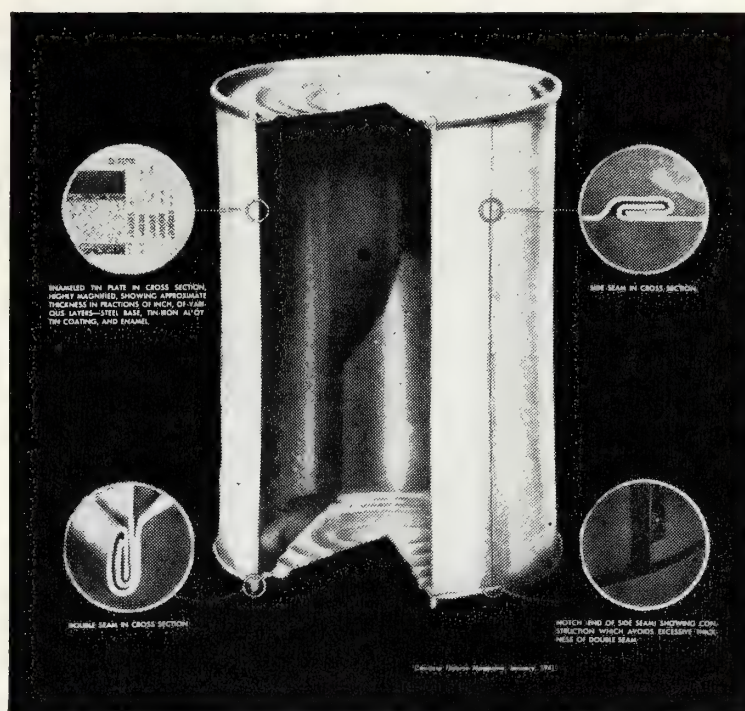
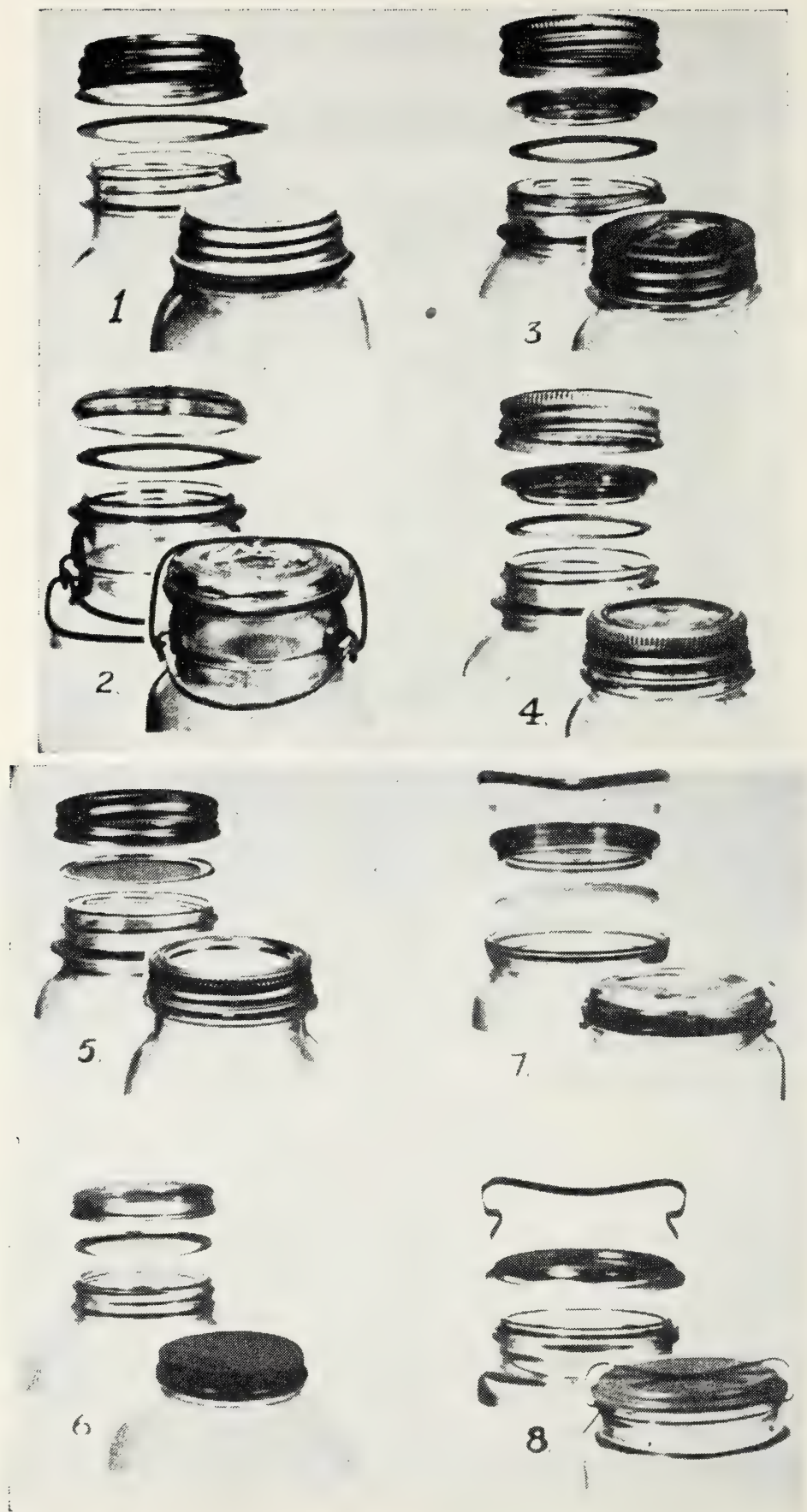


Figure 22-1. (Courtesy of Fortune Magazine, *E. Lowenstein, Artist.*)

Fresh and Frozen Cured Meat. The packaging of fresh raw meat and of ready-to-eat cured meat during the last decade has been the outgrowth of self-service marketing because, in this style of marketing, packaging is essential to protect the meat from filth. In late 1953, 50.3 per cent of the members of the National Association of Retail Grocers were using meat self-service marketing. Throughout the United States at that time, the meat departments of 9,500 stores, including 3,750 independents, were operating on a 100 per cent self-service basis. Transparent films are used for this packaging because consumers insist on seeing the meat they buy.

In respect to quality deterioration of self-service meats, the dealer has only one serious problem—appearance. This is primarily a color problem. Dehydration is indirectly involved because this aggravates the color problem. Selection of packaging materials is done almost exclusively on the basis of the effects of these materials upon the preservation of color in the meat. For the first two days after packaging, a permeable type of package for raw fresh meat seems to be advantageous because, with oxygen in contact with the meat, the red-pigmented oxymyoglobin is preserved on the surface of the meat. For this reason, films which are permeable to gas, such as cellophane (when wet) or cellulose acetate, are usually preferred. The former is generally preferred because cellulose acetate has a high water vapor transmission rate and thus permits rapid loss of moisture from the meat. For preserving red color longer than 48 hours, a film of very low gas permeability, such as a “Pliofilm” or Saran laminate with cellophane, serves better than cellophane alone, especially if the package is sealed under vacuum. In these films, however, the color of the meat during the first 48



(Courtesy Institute of Food Technologists)

Figure 22-2. Eight different styles of home canning caps. 1 and 2. Standard Mason jar caps, 70 mm diameter.

3 and 4. Glass lids, 70 mm diameter, with sealing rings on top of jar finish.

5. Top seal metal lid, 70 mm diameter.

6. Top seal metal lid, 63 mm diameter.

7. "Lightning type" closure, 83 mm diameter, glass lid with top seal ring.

8. "Lightning type" closure, 83 mm diameter, metal lid.

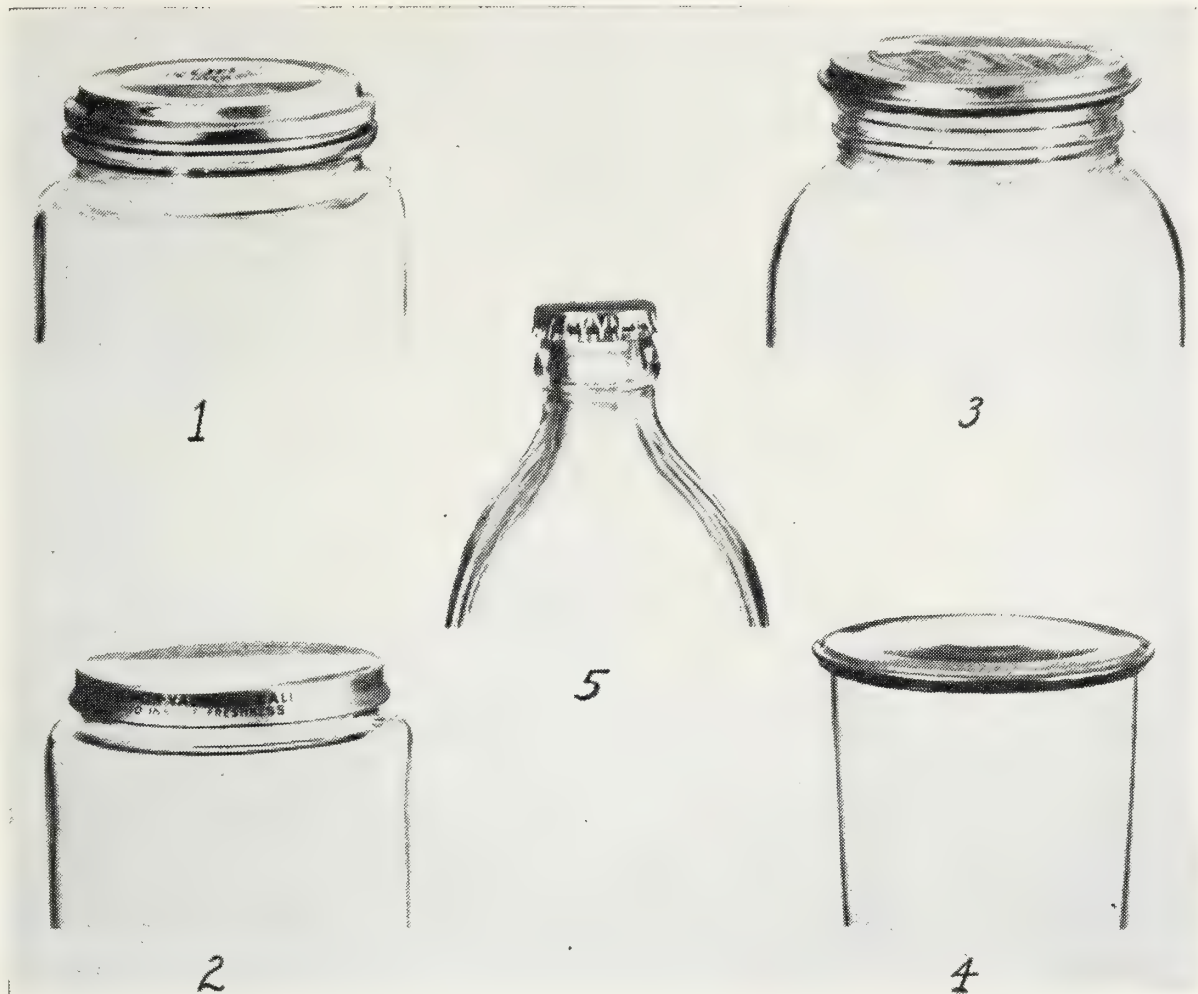


Figure 22-3. Caps commonly used on glass containers in commercial food packing. 1 and 2. Slip-on caps, outside seal, held on primarily by vacuum, 58–83 mm on vegetable and fruit jars; 57–73 mm on tumblers. 3 and 4. Crimped on caps, used mostly on tumblers, 57–73 mm diameter. 3 shows an outside seal; 4. a top seal. 5. Crown cap, no rubber, 26–36 mm diameter.

hours after packaging is not as red as that in cellophane. Cured meats differ in this respect from raw fresh meats; the red color of the former is best retained in the complete absence of free oxygen. For this reason, these items are sometimes sealed under vacuum in packages of cellophane-“Pliofilm” or cellophane-polyethylene laminate. Polyethylene alone, being quite permeable to gas and not being grease-proof, is not a satisfactory packaging material for meat. The color changes just discussed for both fresh and cured meats are explainable on the basis of some unique chemical properties of the heme pigments.

Film breakage also presents a problem for the self-service dealer in meats; however, as a rule, the film outlasts the red color of the meat. Simple films, like cellophane, usually are not required to last longer than two days. The laminates resist breakage better than cellophane alone. A help in preventing film breakage is found in the use of molded wood pulp trays. The tray absorbs moisture and maintains the shape of the package.

Some frozen meats are packaged in transparent films but this practice has not met with wide acceptance because the appearance of the meat is impaired by the formation of frost on the inside surface of the film wherever the film is not in contact with the meat.

Fresh vegetables and Fruits. To a minor degree for sanitary protection of the product, but mainly for convenience, fresh vegetables and fruits are packaged, to a rapidly growing extent, in plastic bags. Polyethylene is very popular for this purpose because of its physical strength and transparency, combined with the fact that it is cheaper than cloth. About 40 per cent of polyethylene bags in 1954 are used for produce. "Pliofilm" (rubber hydrochloride) also is used for this purpose—much of it in "stretch wrapping." It is claimed that 65 pounds of "Pliofilm" will individually wrap a carload of lettuce. Produce packaged in these film materials is cooled after crating by vacuum treatment, promoting evaporation of free moisture from the surfaces of the produce.

Properties of Films. The importance of various physical and chemical properties of film materials should now be apparent to the reader. To explain briefly how objective measurements of those properties are made, which are of greatest importance in the field of food packaging, we shall quote from a non-technical exposition on the subject which was issued in January, 1954, by Chester Packaging Products Corp. as an "Informational Bulletin" on polyethylene. Editor, Gene Liberty. One section, that on "pH", is omitted.

THE AGE OF PROTECTIVE PACKAGING

"The vocabulary of the testing laboratory has become part of the everyday speech of the converter. In previous years, price, supply, delivery, demand, and the conversion of existing equipment to the handling of new films were the major uncertainties that converters faced. Today, in our undustry's Age of Protective Packaging, there are additional concerns. Flexible films are no longer thought of in terms of simple containers or wrap-around covers. The demands of our complex technology have caught up to them.

"We ask new questions: What is the burst, tear, WVT, tensile, grease-proofness? Are the pH, aging, and oxygen transmission satisfactory? Will it stand up to sunlight and have a long shelf life? Both industry and government now draw up exacting specifications of physical and chemical properties that are required for packaging films. As competition intensifies, these properties often decide whether a sale is made or lost.

"This issue of the Bulletin is planned as an abridged and simplified guide sheet, to give readers without too much technical experience an insight into some of the methods of determining protective properties of flexible films. Although we verified outside sources and literature, most of our information is derived from the day-to-day practices of our own laboratory.

ARE PUBLISHED FIGURES OF PHYSICAL PROPERTIES RELIABLE?

"Generally, published figures of physical properties are the findings of conscientious laboratory testing, but standards, personnel, equipment, and methods vary from laboratory to laboratory often producing results that conflict. Small changes in

a single test procedure can yield answers that are surprisingly far apart, and only under carefully controlled conditions can two laboratories duplicate their efforts.

Until the time that technical societies succeed in universally standardizing test procedures for flexible packaging, it is prudent never to accept published figures at value. Figures alone are misleading; they have significance only when all the details of the test procedure are known.

WATER VAPOR TRANSMISSION

“Water vapor transmission (WVT), sometimes called moisture vapor transmission, (MVT), is a measurement of the weight of water vapor that will pass through a given area of packaging material every 24 hours. WVT refers to the passage of water *vapor* and should not be confused with waterproof, which describes the resistance of a sheet to *liquid* water.

“In the test, an aluminum cup is filled with a desiccant, i.e., a substance that absorbs water readily. The packaging material to be tested is then sealed air tight to the top of the cup with wax. Moisture can only get to the desiccant by passing through the sheet, and the amount of moisture which passes through and is held inside will determine the WVT of the sheet. The entire cup assembly, containing the cup, desiccant, packaging material, and sealing wax, is next placed in a humidity cabinet that circulates hot moist air. One of the widely used cabinets in this work is the General Foods Humidity Cabinet, operating at 100°F and 90% relative humidity.

“Some of the moisture in the cabinet will penetrate the sheet and be absorbed by the desiccant. The cup assembly is weighed every 24 hours to determine the amount of moisture gained. When this gain becomes constant and the cup assembly becomes heavier by identical amounts for each 24-hour period, the test is concluded. The WVT is calculated from the daily weight gains and the known area of the sheet.

“A typical WVT value for 1½ mil polyethylene sheet tubing might read 0.94 gm/100 in²/24 hrs. This means that at 100°F and 90% relative humidity, 0.94 gms of water vapor will pass through a polyethylene sheet 100 square inches in area every 24 hrs. Some laboratories report WVT in gm/m²/24 hrs., where m² is square meters.

BURSTING STRENGTH

“A sample is clamped between the two ring shaped jaws of the testing machine and rests above a rubber diaphragm contained in the lower jaw. The diaphragm is connected to a hydraulic system and can be blown up like a piece of bubble gum by increasing pressure on the system. As more pressure is applied, the specimen, constantly being pushed by the expanding bubble, will burst. A dial gauge records the exact pressure which bursts the sample.

“Most laboratories have a Mullen Burst Tester and “What’s the Mullen?” is frequently used to request information about bursting strength.

“Bursting strength is reported in either points or pounds per square inch; both units are approximately equal.

TENSILE STRENGTH AND ELONGATION

“Although several machines made by different firms are used to determine tensile strength and elongation of thin films, a general test procedure can be outlined to describe all of them: Samples are cut in long narrow strips, for example, 7" x 1", and clamped between two jaws. A constantly increasing load is applied to one jaw, moving it away from the other. The sample, which is held between the jaws, is literally pulled apart. First, it starts to stretch, and when it can stretch no further, it breaks in two.

The minimum load required to break the specimen determines the tensile strength, and the amount of stretch just at breakage determines the elongation.

Tensile strength is reported in pounds per inch width (where width refers to the width of the sample) or in pounds per square inch. When pounds per inch width is used, the term breaking load is often substituted for tensile strength. Elongation is reported in inches or percentage. To illustrate, if the original distance between the clamps is 5" and the distance at breakage is 20", the elongation equals 15" or 300%.

INTERNAL TEARING RESISTANCE

"The simplest way to determine internal tearing resistance is on an Elmendorf machine. The sample is clamped between two sets of jaws, one movable and the other fixed. A pendulum is attached to the moving jaw, and when it is released, it plunges downward, carrying the jaw and tearing the sample. A pointer and dial on the pendulum indicate the internal tearing resistance.

"The operation of an Elmendorf may be compared to clamping a sample in a bench vise and tearing the projecting piece with your fingers. The vise is the fixed set of jaws, your fingers are the movable set, and your forearm, which supplies the motion, is the pendulum.

"For some films, the Elmendorf is unsatisfactory, and more complex technics of determining the tearing resistance are necessary.

"Internal tearing strength is expressed in grams per sheet or pounds per inch.

GREASE RESISTANCE

"Greaseproof tests attempt an accelerated comparison of the rate at which oils and greases, such as those found in foods and industrial preservatives, penetrate packaging materials. A 4" x 4" sample is placed on white paper, and a measured volume of test reagent is poured on top of the sample. The reagent is generally colored turpentine or a solution of grease in turpentine. Periodically, the white paper is examined for small stains to see if the reagent has penetrated the sample. As soon as a stain is discovered, the test is terminated.

"The time elapsed from the start of the test to the appearance of the first stain is known as the transudation time. Depending on the reagent and the severity of the test, acceptable transudation times vary from 15 minutes to 24 hours.

GAS PERMEABILITY

"The ability of a packaging film to permit or prevent the transmission of a gas frequently decides whether the product enjoys a long or short shelf life. Typical problems related to gas permeability are oxygen induced deterioration of cheeses, dried whole milk, and fats; product contamination through absorption of foreign odors; excessive loss of desirable odors from substances like bath salts or lotions; and tarnishing of silverware. At times, high permeabilities are desirable as in the "breathing" of fresh produce.

"In the test procedure the film is sealed across an opening in a vacuum chamber equipped with a pressure gauge. The gas, which may be air, oxygen, hydrogen, carbon dioxide, etc., is passed through the film into the chamber. As the chamber slowly fills with gas, the pressure rises and gauge readings are made at time intervals. When a leveling off period occurs and the same volume of gas enters every hour, the test is completed. The film will exhibit different permeabilities to different gases.

"Gas permeabilities are reported in cc/100 in²/24 hrs. (cc is an abbreviation for cubic centimeter, the scientific unit of volume. One quart contains approximately 945 cc.).

ACCELERATED AGING

"During its life, a package must resist a combination of atmospheric influences which eventually age and destroy it. These influences are made up of varying proportions of humidity, heat, cold, sunlight, pressure, and gases. In an accelerated aging test, the film or package is subjected to harsh extremes of heat, cold, humidity, etc., in order to accelerate the changes that would take place under the less severe conditions of normal service.

"A typical test is to alternately expose a sample to wet and dry heats such as 24 hours at 160°F. in a dry oven. This wet heat/dry heat cycle is repeated as often as the test conditions require. If necessary, other factors like low temperatures, ultra-violet light or oxygen exposure are introduced into the cycle. After each cycle is completed, the film or package is examined for product deterioration, changes in weight and dimensions, dulling, crazing, warping, and discoloration.

"It is difficult to predict the shelf life of a packaged product solely from the results of accelerated aging tests unless some correlation can be made based on years of field testing. Many laboratories agree that shelf life is best determined by periodic examination of packages that have been placed on shelves in different parts of the country or world. This is an unfortunately long but always reliable procedure. However, accelerated aging tests are valuable in comparison testing, where different films are simultaneously put through aging cycles to ascertain which of them will best withstand the corrosions of the atmosphere."

Brief descriptions of the physical properties of five types of plastic materials, which are important in food packaging, are given in Table 22-11.

The excellent plasticity of polyethylene film at low temperatures makes the film well suited for packaging frozen foods when the film does not have rigid support against breakage. An interesting new use of polyethylene, laminated with cellophane with a special low temperature adhesive, is in pouches for packaging individual servings of orange juice concentrate (2½ ounces per package). The pouches are heat sealed.

Fluid Milk. Probably the most widely used food among those which are distributed in a nonsterile state and which are packaged for sanitary protection, is fluid milk. Packages used are glass bottles with paraffin coated paperboard or foil closures and paperboard containers coated with paraffin or plastic. To measure the sanitary protection that is afforded to the milk the package is evaluated from the standpoint of two features, namely, (1) protection of the pouring lip and (2) interior sterility. Although fluid milk is a nonsterile product, the number of viable bacteria in it is carefully controlled. Maximum numbers are specified in control regulations which are enforced by public health officials. Therefore, it is required that the interior of fluid milk containers, before filling, be either sterile or nearly sterile so that the bacteria count of the milk will not be noticeably increased by bacteria from the container. A container is regarded as sterile if it can be rinsed with sterile water without imparting any viable bacteria to the water. Sterility of glass milk bottles is ensured by thoroughly washing the bottles just before filling with a hot antiseptic solution and rinsing with sterile

TABLE 22-11. PHYSICAL PROPERTIES OF FILM MATERIALS

Material	Thickness (in.)	WVT resistance 100°F	Gas permeability	Tensile strength	Elongation	Internal tearing resistance	Grease resistance	Flexibility at 0°F	Heat sealing	Transparency
Cellophane	0.0008-0.0017	Good	Low (dry)	High	Low	Low	Exc.	Poor	Yes (when coated)	Exc.
Cellulose acetate . . . . .	.0008-.0025	Poor	High	High	Low	Low		Poor	No	Exc.
Polyethylene . . . . .	.0002-.004	Good	High	Fair	High	High	Poor	Exc.	Yes	Fair
Vinyl compounds . . . . .	.0005-.002	Exc.	Low	High	Low (nonplasticised)	Medium	Exc.	Good	Yes	Good
Rubber compounds . . . . .	.0002-.0025	Good	High	Good	High	High	Good		Yes	Good

water. With the most improved technic in washing, a detergent is added to the washing solution automatically, keeping the solution at constant strength. With paper milk containers, the final treatment with hot paraffin or hot plastic produces the sterile condition although, prior to that, the paperboard, of which the containers are made, is produced from virgin pulp by the sulfite process and under regulated calendering conditions which ensure a very low bacteria count in the board and complete absence of bacteria of types that have sanitary significance in milk. The paraffin or plastic coating of some containers is applied in the dairy plant in the container fabricating operation just before the containers are filled; other containers are coated in a central fabricating plant before being shipped to the dairy. In the latter case, each container is tightly closed immediately after the coating is completed to prevent the entrance into the container of bacteria or other contaminants during shipping and handling prior to filling.

By "protection of the pouring lip" is meant the coverage, immediately after the container is sterilized and immediately after it is filled, of all surfaces near the pouring opening, which might be touched by the milk as it is being poured. This is to prevent these surfaces from acquiring unsanitary contaminants which would be imparted to the milk when it is poured. It is accomplished on glass bottles by having the lip of the bottle overlapped either by a specially designed combination plug and cap or by a separate hood. On paper containers, the coverage is afforded by either an extension of or an attachment to the plug, which is attached to the container in a hinged manner.

To avoid holding milk too long, that which is left on the shelf after 24 hours is removed and applied to other use than that of fresh milk.

Salad Dressing. A stock rotation program of a different sort than that used with milk is employed with salad dressings and products of a similar degree of stability. Principally, glass containers are used for such products and code marks are put on the labels, either by printing or by perforating, to indicate the date of manufacture of the product. The perforating method has generally been used in the past because of the difficulty of printing on varnished labels. By a new technic, printing is now being done, providing both speedier operation and improved legibility over the perforated code. The shelf life of these products, of course, is much longer than that of fresh milk, being ordinarily counted in terms of weeks.

Basic Factor No. 3—Resistance to Impact Injury. It would be a happy circumstance if every container could be made physically strong enough to resist breakage under any impact. Flexible packages, folding boxes, glass containers, in fact, practically all containers except those made of metal, as a rule, show little visible effect of impacts which are not severe enough to break the containers; metal containers, however, may re-

ceive dents, which are permanent disfigurations, from impacts which fail both to break open the package or to render its seal ineffective.

Evaluation of the probable severity of impacts which a container will have to suffer is a necessary step in selecting the type of container to use for a product. Not only must the material of which the container is to be made, along with the design and the type of construction, be considered, but also the nature of the product to be contained. With a liquid product, the problem of the effect of impact upon the container is more critical than with a dry product because liquid spilled from a container usually destroys the usefulness of other containers with which the liquid comes into contact. When a dry product is spilled, surrounding containers often are not seriously affected. Pouches of flexible material are often not affected by impact until the impact squeezes the pouch to the bursting point. In paperboard containers, rectilinear containers are more resistant to most types of impact than curvilinear containers, although, in some cases of point impact, the curvilinear might show superior resistance. Multi-ply folded ends lend strength to paperboard containers but such ends are not as strong as a single ply end of equal thickness unless the plies of the folded end are fastened together with adhesive.

In metal cans, which are the most resistant of the retail food containers to physical abuse, the hermetic type of container presents the most serious problem. When a hard object strikes a double seam a blow, such as may occur when a filled can is rolled down a steep decline and suddenly stopped by coming into contact with a metal barrier, the conformation of the seam and its gasket may be sufficiently disturbed to cause a leak which would admit air to the can and might even admit spoilage bacteria. Such treatment is not likely to break a well soldered sideseam; however, a current move to reduce the use in cans of metals which become critical in times of emergency, poses a question as to the resistance offered by solderless sideseams to the injurious effect of impact. For certain nonfood products, cans with "doped" or cemented sideseams have been used for a number of years. Such cans, if the sideseam compound is innocuous when in contact with foods, are satisfactory also for foods that are not processed for sterilization. A sideseam compound that is suitable for use with foods, and which will withstand heat processes for sterilization, however, has not been brought to a practical stage.

Compounding a sideseam is a much more difficult problem than compounding a double seam for the reasons that: (1) the sideseam, being straight and being made with one less fold than the double seam in the stock forming the outer hook, does not have the assistance of the curvilinear shape and of the extra fold of stock which the double seam has in preventing unhooking and in preserving the orientation of the hooks in respect to one

another, (2) the side seam cannot readily be rolled to tighten it after it is formed, (3) the side seam will not stand tightening to the same degree as the double seam on account of the greater tendency of the former to become unhooked from tightening, due to the mechanical characteristics mentioned in reason No. 1, (4) the side seam cannot be hooked over its entire length; at each end, it is simply lapped to allow for doubleseaming, (5) the side seam is more susceptible than the double seam to severe deformation by impact, due to the mechanical characteristics mentioned in reason No. 1. For these reasons, it is very difficult to formulate a workable compound or cement containing a sufficiently large proportion of inert insoluble substances to hermetically seal a side seam and to possess reasonable resistance to leakage as a result of deformation of the seam.

While the use of a compound in side seams saves solder, more important is the saving of tin on the plate that is made possible. For food products of a noncorrosive nature, the only reason that a tin coating is required on the plate is to make it possible to solder the side seams of the cans. Welding of side seams on a commercial scale is possible but this is more expensive than compounding. Reasons for this will be stated later.

Basic Factor No. 4—Efficiency of Interior Surface. The interior surface of any food package must be compatible with the contents, that is, it should be of such a nature that any chemical or physical reaction that takes place will have a minimum effect upon the quality of the food. Most materials of which food containers are made are relatively inert chemically. With food products in the dry state, the chemical nature of the container material is of little moment because the food itself is inert. Paper and synthetic plastic are the most commonly used materials for these foods—untreated when the container is to serve for a short time only or when change in moisture content of the food during storage is immaterial. Where it is necessary to protect the food against change in moisture content, plastic material, if not naturally impervious to moisture, or paper, is treated with wax or other substance, often plastic, which renders the package moisture-resistant. While this has nothing to do with chemical reaction between the food and its container, it may be said to be concerned with physical reaction between them, in which the container material either takes from the food or imparts to it water.

Foods in the range of moisture content of 20 per cent and higher are in a class which react, both physically and chemically, with the container. It is with these foods that the major problems dealing with the inside surface of the container exist. Of course, the necessity of protecting the food, either of dry or moist type, from absorption of foreign odor or flavor or of toxic fumes is always present. The problem involved here is concerned with the inside surface but is concerned even more with the packaging ma-

terial in its entirety. The body of the material must contain nothing which is capable of imparting to the food either toxicity or foreign odor or taste; no food packer and no container manufacturer would think of attempting to protect a food product from dangerous or undesirable elements existing within a packaging material by superimposing an innocuous surface coating on the inside of the package to serve as a mask for the dangerous or undesirable elements. Such coatings are employed, however, to shield food from a container material which is capable of reacting chemically with the food in a manner which has only economic significance, accompanied by no health hazard and by little or no quality deterioration of the food.

Under Principles of Grading, page 706, is given a pattern of grading principles which illustrates how the inside surface of one type of container, the paper milk container, might be evaluated. This pattern is simplified by acceptance of the assumption that chemical reaction is no problem with either the paperboard or the coating material; thus the rating is concerned only with physical reaction between the container and the milk, a liquid product. Basically, this constitutes a rating of the efficiencies of different types of coatings in imparting moisture resistance to containers of various designs when the coatings are applied in various ways and in various stages of fabrication and handling. If container materials are being considered which are not known to be free from toxic ingredients or to be chemically inert in respect to milk, the problem of evaluation would have numerous additional ramifications.

Problems with Steel. The so-called "tin can" is a container made of steel plate on which is a very thin coating of metallic tin. The necessity to conserve tin during World War II led to the practice of using thinner and thinner coatings of tin on plate used for food containers. The technology involved in this movement is very complex from the standpoint both of can manufacture and can use. Progress has been rapid, however; cans can be made without tin that are satisfactory for nonsterilized foods as well as for some heat processed foods. The cans must be coated on the inside with an organic material which is inert in respect to the food product to be held and on the outside with a substance which will prevent rust. When the side-seams are welded, these coatings, at least on the areas adjacent to the side-seams, must be applied after the body of the can is formed because, when applied previously, they do not withstand the heat of welding. This operation, along with the fact that maximum speed in welding is substantially less than customary soldering speed, makes the cost of welded cans greater than that of soldered cans, notwithstanding the fact that no tin is used in the welded cans. Thus, while welded cans are used commercially in Europe, they have not yet been found to be economically feasible in the United States. The industry constantly seeks to remedy this situation.

Compounded, or cemented, sideseams can be made at high speed and with no accompanying problem in relation to coatings. The formulation of a side-seam compound for cans of food to be heat processed, however, is not perfected. Sideseams of tinless cans, made of CMQ (can making quality) of black plate, can be soldered at high speed but often with injury to enamel coatings and with corrosion of the plate due to use of flux having highly corrosive properties. Moreover, adhesion of enamel coatings to this plate is very difficult to secure. Black plate can be made more receptive to enamel coatings by a chemical treatment but all such chemical treatments now known increase the difficulty of soldering. Thus, soldered tinless cans also are not yet feasible for wet food products.

Steel plate can be used successfully in containers for wet food products only when the steel is covered with a coating either of a metal of low chemical reactivity, such as tin or aluminum, or of an organic substance, or of both together. The organic coating substances may be composed of either synthetic or nonsynthetic materials. They may be mixtures of thermoplastic resins and plasticizers which are applied in the melted state and allowed to solidify in cooling, or they may be substances that are baked to “set” them after they have been applied as coatings. Coating materials that require baking are formulated either as cooked mixtures of oil and resin or as uncooked solutions of resin and plasticizer. The coatings problem exists with the all-metal can and with metal caps of glass containers. There is no surface problem with the glass portions of food containers.

Chemically, tin used for food cans must contain no more than the amounts of impurities specified by Federal Agencies as maximum tolerances. Values contained in regulations on the composition of Grade A pig tin are given in Table 22-12. Thus, toxically, tin provides a safe inside surface for food cans. Were it possible to produce perfect coverage of steel with tin, there would be practically no chemical reaction between food products and

TABLE 22-12.
FEDERAL REGULATIONS ON COMPOSITION OF GRADE A PIG TIN

Gov't. No.	Composition limits	Impurities (%)										
		Sb	As	Pb	Bi	Cu	Fe	Ag	S	Co and Ni	Cd	Zn
Treasury Procurement Division U. S. Spec. S-14 (3)	99.80% Sn (minimum)	0.050	0.040	0.050	0.015	0.040	0.015	—	0.010	—	—	—
Fed. Spec. QQ-T-371a (1)	99.85% Sn (minimum)	0.040	0.050	0.050	0.015	0.040	0.015	0.001	0.010	0.010	0.001	None

Courtesy, Tin Research Institute.

metal. Because of exposure of minute areas of steel, however, galvanic couples of tin and iron are established in contact with the food product, which serves as an electrolyte, and a solution of either tin or iron results. The rate at which this solution takes place depends upon the oxidation-reduction potential of the electrolyte, the temperature, and the presence or absence of other metallic elements in the tin plate. Low concentrations of certain elements, some metallic, some metalloidal (silicon, phosphorus, chromium, nickel, copper, molybdenum are of greatest significance), cause the reaction to go slowly. Only within the last 25 years, during which the cold reduction process for tin mill sheets has been in use, was it learned how to produce the proper degree of hardness and proper surface characteristics for satisfactory fabrication of cans without the use of comparatively high concentrations of metalloids in the steel. Thus, cold reduction and temper rolling of steel sheets have led to the solution of many problems associated with corrosion of tin plate by foods.

There are two ways of controlling the kind of corrosion that results in reduced shelf life for canned foods; sometimes one is used, sometimes the other, depending upon prevailing conditions, both economic and political, as well as upon the nature of the product being packed. The first method is to use a heavy enough tin coating to retard corrosion. This is always a feasible method provided the necessary tin is available, for, notwithstanding the presence of minute exposed areas of steel through pores in the tin coating, tin provides protection against corrosion by retarding the solution of the iron, and the extent of retardation of solution is proportional to the thickness of the tin coating, within the range of thickness that is used on plate for cans, namely, up to about 2 pounds of tin per base box (62,720 sq in. of coating) of plate. While this procedure is always feasible from the standpoint of preventing destructive solution of iron, it is not feasible with some products from the standpoint of the preservation of a desirable appearance of the product or of the interior surface of the can.

Some products cause the surface of tin plate, regardless of the thickness of the tin coating, to take on an undesirable appearance, due to chemical reactions between the product and the metal. With low-acid products, which liberate considerable quantities of sulfur-bearing compounds when they are heat-processed, dark-colored sulfides are formed. Prominent in this class of products are corn and seafoods, particularly shellfish. The more acid foods produce a mottled surface appearance on the tin plate, sometimes referred to as spangling or etching. Foods containing red pigment lose much of their color when held in contact with plain tin plate, that is, plate on which the tin is not covered with a coating of lacquer or other organic material. Because of these effects of holding in plain tin cans, the inside surfaces of cans for these products are lacquer coated, regardless of how heavy the tin coating on the plate may be.

Baked lacquer (or "enamel," as it is usually called) coatings on the interior surfaces of food containers retard corrosion of the tin plate; thus, the second way to increase the shelf life of a product is to use lacquer coatings. This is true especially with tin plate of higher temper which is used for the less corrosive, low-acid, products. Thus, for products that require enameled cans to ensure a satisfactory appearance of either the food or the inside surface of the container, the enamel coating may not only perform that purpose but also extend the life of the canned product. Lacquer coatings are often used however for the sole purpose of obtaining satisfactory shelf life when the tin coating is too thin to perform this purpose alone. With the relatively nonreactive products, such as corn, peas, meat, and fish, therefore, as well as with the moderately reactive products, such as peaches, pears, citrus fruits, pineapple, tomatoes, green beans, and beets, lacquer is substituted for tin when conditions make it desirable or necessary to conserve tin. (In beets, it preserves color, also.)

Conservation of tin on a major scale in the manufacture of tin plate has been made possible by the building, within a period of just 15 years, of capacity to produce electrolytically coated tin plate at a rate equal to 90 per cent of the world's maximum rate of production of tin plate. By the older method of coating, known as the hot-dip method, it has never been found practicable to produce plate having less than 1.25 pounds of tin per base box, whereas, by electroplating, the minimum limit of tin for satisfactory coating is nil. Electroplating equipment now in operation in the countries of the Western World consists of 41 production lines, of which 33 are in the United States, 3 in Great Britain, 2 in Canada, and 1 each in France, Belgium, and Brazil. The United States production capacity of electrolytic plate, based on No. 50 plate which carries .5 pound of tin per base box, is about 3,845,000 long tons and the capacity of other countries is about 910,000 long tons per year.

Properties of Enamel Coatings. Studies are being made continuously of the properties of solvents, oils, resins, and plasticizers used in enamel coatings to ensure that the coatings are chemically inert to the food products with which they are to be used and are incapable of imparting any harmful or disagreeable characteristic to the food. Among the properties of a coating which are most important to ensure that it will function as intended is one which depends upon both physical and chemical factors. It is the property of adhesion. The ability of the coating to adhere to the plate depends not only upon the composition of the coating material and the procedure followed in applying the coating, but also upon the surface characteristics of the plate, which, in turn, are determined by the composition of the steel, the finish of the steel, and the manner in which the tin coating is applied and finished. These characteristics also demand constant study to determine the effect of every variation in plate fabrication procedure upon the per-

formance of coatings. Failure of a coating to perform properly means loss of food, which has not only been produced, but also canned.

There are three ways of applying tin electrolytically, differing basically from each other in the type of electrolyte used. The essential steps of the operation, including cleaning, plating, fusing, oiling, etc., are, to a large extent, performed differently in the various methods. Any one of these variations may importantly affect enamel adhesion and, finally, the baking of the lacquer itself is a most critical step. The baking technic must be correlated with all of the other factors to which reference has been made, including, of course, the end use of the container.

The growth in production of electrolytic tin plate, accelerated greatly, of course, by circumstances in World War II, has been astounding. From practically nil in 1941, in ten years electrolytic plate production in the United States accounted for more than 60 per cent of the total tinplate production. During most of that period, No. 50 plate (0.5 pound per base box) was first in quantity, No. 75 (0.75 pound per base box) was second, and No. 25 (0.25 pound per base box) was third. During the last few years, No. 25 has become first by an ample margin, No. 50, second, and No. 75, third. Substantial quantities of No. 10 and No. 20 plate are also now produced and plate in these categories is increasing in percentage of the total. Another type of plate which is coming into use on an important scale is differentially coated, that is, plate with a thicker coating of tin on the one side than on the other. The purpose of this plate is to provide a thick coating of tin on the inside of the can for protection against corrosion by the food and a thin coating, probably a No. 25 coating, on the outside, which is ample for protection against rusting under normal storage conditions. It is expected that, generally, in differentially coated plate, the lighter coating will be .25 pound per base box or less; the heavier coating generally 1.0 pound per base box. Differentially coated plate is used to make cans for processed foods; up to this time, most of these have been for tomato juice, although, as more differentially coated plate is produced, it will be used for other products of moderate or high corrosive activity.

The problems with steel, including those on organic coatings, have been discussed in direct reference to cans. The discussion applies also to metal closures for glass containers, except that part which pertains to the fabrication of seams. Problems of corrosion in metal caps differ but little from those in cans, although measures which have been found to be effective in retarding corrosion of the steel in cans seem not to be so effective for closures. Kohman³ believes that the mechanism of corrosion in metal caps includes the passage of hydrogen ions, and possibly of sodium and potassium ions, through the seal of the jar, enabling a galvanic couple to be established with its cathode outside the jar and its anode inside the jar. The

cathode, being the raw steel cutedge on the periphery of the cap, is of comparatively large area; therefore, corrosion is accelerated.

Basic Factor No. 5—Absence of Handling Problems. Most modern food packaging operations employ machinery for carrying out the various steps. The relative quantity of machinery required, and the relative simplicity or complexity of the machinery required by one container compared to that required by other containers, measure the advantages and disadvantages of that container in respect to others that might serve the same purpose. This characteristic, of course, pertains primarily to filling, sealing, and conveying machines and accessory equipment.

The conditions surrounding the projected use of a container often are important in this phase of a container evaluation. If the container would displace another container in the application for which it is considered, for example, in the replacing of one for the other among metal, glass, and paper containers, the question would be faced as to how much new handling machinery would have to replace the old but, if an entirely new operation were under consideration, the question would be whether or not a new installation for one container would cost less than, or have other advantages over, a new installation for another container. Sometimes the ease with which accessory devices or gadgets which may be considered important to the operation can be incorporated into the handling equipment is considered in weighing relative advantages of equipment. For instance, a magnetic attachment for removing tramp metal from the food being conveyed to the filler or an x-ray attachment for detecting foreign substances in a filled container or for checking the fill of the containers may have a substantial bearing on over-all plans for machinery. Or, where rigid containers are involved, the requirements of machinery for uncasing and washing containers may have a substantial influence on the equipment layout.

Speed of filling and sealing naturally weighs heavily in consideration of the handling machinery factor in container evaluation. With one-line filling and sealing speeds approaching 800 per minute, competition amongst different types of containers is keen and correct decisions on these matters are important.

Machinery now is available even for filling 55-gallon drums with liquid automatically at a rate of two drums per minute.

Basic Factor No. 6—Space and Other Storage Requirements in Filling Plant and in Distribution, including Weight. The material of which the containers are made, the shape of the container, and the location of the container fabricating operations are the attributes which decide the container rating under basic factor No. 6. The greatest space-saving step for the packing plant that uses rigid containers is that of receiving of container-making material in the form of container blanks and carrying on

the final fabricating operation in the packing plant, preferably in tandem with the filling step. This system is used extensively with paperboard containers and to a minor extent with metal containers. Nonrigid containers, being collapsible, may be prefabricated without a sacrifice of storage space in the filling plant. Of the rigid containers that are prefabricated, those of rectilinear outline have an advantage over those of curvilinear design, such as cylindrical containers, from the standpoint of space requirements. Further, from the standpoint of both space requirement and weight, metal containers have an advantage over glass containers and paper containers have an advantage over metal and glass containers.

Basic Factor No. 7—Special Features Related to Performance for Packager. A container may have attributes which, while they are unessential for excellent performance on the part of the container, do add substantial esthetic or utilitarian value to the container. Such an attribute might be one that permits the application of a special type of label which cannot be used on other containers intended for the same purpose. This label might have unusual attractiveness and it might also enhance the utility of the container in some way that is 'beyond the call of duty.' The degree of acceptability of printing or lithography by a film may also be a case in point; for example, polyethylene may present more of a problem in this respect than some other film material.

Metal foil may be laminated in an overwrap or be used as a tray for the purpose of protecting against transmission of gas and moisture, but foil used in these ways is said also to accelerate freezing and thawing of the food. This is an added point of merit.

A canner, using conventional methods of processing, may contemplate converting his operation at a future time to one of aseptic canning. In choosing a container for his product, he would consider attributes which make the container adaptable to the aseptic type of operation.

Consumer Acceptance Factor No. 1—Size. The attribute of size has a bearing on the rating of a container only when a type of container which is customarily in use for certain purposes is being considered for a new use. The container would currently be available in certain sizes and it would be necessary either to use the container in one of the available sizes or to assume the cost of initiating its manufacture in a new size. The decision must be made after consideration of the consumers' desires.

Consumer Acceptance Factor No. 2—Ease of Opening. In its bearing on consumer acceptance, easy opening carries great importance. Certainly, it receives as much attention in the development of a container as any other consumer acceptance aspect. Without undertaking a review of the methods of opening containers, let it be said that improvements in cans to facilitate opening occur quite infrequently; those in glass jar clo-

tures perhaps somewhat more frequently, and those in fiber and plastic containers are remarkably frequent. Screw caps and crown caps are used on both glass and metal containers; also, screw caps are used on some fiber containers. These are removed with comparative ease by gadgets that are common household articles. The most conveniently opened hermetic can is the key-opening scored can and the most conveniently opened hermetic glass container, aside from the rubber gasketed screw cap container, is the press-on pry-off rubber gasketed side and/or top seal container. Devices to facilitate the opening of fiber and plastic containers are many and of widely varied design.

Consumer Acceptance Factor No. 3—Reseal Features. Milk containers must be provided with a means for resealing. On paper containers, a part which is hinged onto the container serves as a reclosure plug. The desirability of resealing many other products helps to determine the type of container that is used for these products. For coffee, the key-opening "collar type" can is generally used, the "collar" being a band encircling the inside periphery of the can, over which the side wall flange, or skirt, of the top end, after its removal, fits for reclosure. Where glass containers are suitable for hermetically packed products, the press-on cap provides a very satisfactory reclosure. Special reclosure can tops made of aluminum are now offered for sale to the consumer for use on cans after the regular top has been removed. Screw caps of either metal or plastic serve admirably for reclosing the containers fitted with them. These are practically never used commercially for containers that are to be hermetically sealed.

Consumer Acceptance Factor No. 4—Pouring Qualities. A sharp edge serves best as a pouring edge because it cuts off a stream of liquid abruptly, preventing dribbling and running down the outside of the container after pouring has ceased. A sharp edge which is likely to be touched in handling, however, is hazardous because it may cut the hand. Metal and paper edges often can be turned in so as to leave a sharp edge where it can serve to cut off a stream in pouring and still not be exposed to contact with the hands.

In milk containers, if facility to separate cream from milk is regarded as desirable, the container will be evaluated in that respect under Pouring Qualities.

Consumer Acceptance Factor No. 5—Space Saving in Consumers' Premises. Shape of the sealed container decides everything in this phase of container evaluation. Rectilinear outline, combined with flat ends, is the ideal and merits the highest rating. Other shapes merit lower ratings, which depend upon the extent of departure from the ideal.

Consumer Acceptance Factor No. 6—Light Protection. Light accelerates deterioration of quality in some food products; for example, oxida-

tion reactions which impair the flavor of milk and the color of cured meat. A container that protects such a product from light of the wave lengths which are injurious to it has special merit for that product. Amber glass milk and beer bottles and opaque paper milk containers fall in this category.

Consumer Acceptance Factor No. 7—Transparency. As implied in the last paragraph, transparency at times is undesirable from the standpoint of quality preservation of the food product. In fact, transparency is probably never helpful to quality preservation. Generally, however, it is not harmful and, in view of the fact that the consumer is always pleased when he can see what he is buying, the transparent package is considered to have a sales appeal which the nontransparent package does not have.

Consumer Acceptance Factor No. 8—Tamperproofness. All containers holding sterile food may be said to be automatically tamperproof because, if the seal is broken, spoilage sets in as a result of bacterial contamination. With nonsterile foods, however, a means of betraying tampering with the protective features of the container is desirable to avoid the possibility of using food into which filth may have been introduced. A container for such foods is less than adequate unless it is so constructed that, if the package, while containing the food, had been opened and reclosed, that fact will be revealed by the exterior appearance of the container.

Consumer Acceptance Factor No. 9—Protection of Contents from Physical or Chemical Change. The degree of protection from physical and chemical change afforded by a container to its contents is indeed a major point for consideration by one who is selecting a container for his product. However, the distinction in this respect between two types of containers, both of which are suitable in other respects for holding the product, is not great. It is usually a question of the length of time during which protection will be effective. Furthermore, the production costs of the container which is capable of giving longer protection usually are no more than the costs of the one which gives protection for a shorter period of time. The difference lies primarily in "know-how," that is, knowing how to make the better container.

Except in so far as light effects enter the picture, glass, being inert to foods, gives excellent protection from physical and chemical changes. Problems involved in chemical reactions between foods and the metal caps of glass containers and between foods and metal cans were discussed under Basic Factor No. 4. A problem associated with glass containers, which was not discussed in that section, is that of air seepage through the seals of metal caps. Air entering the container during storage is responsible for producing browning or graying of the portions of food near the caps. Kohman⁴ attributes this darkening to ferric iron compounds which are produced by the oxygen that seeps through the seal. Livingston *et al.*⁵ found that the amount

of discoloration at times could be correlated with the amount of iron present but found that a similar situation existed with other metals. They found also that gradations in the amount of discoloration in different portions of the contents of a glass container are not necessarily accompanied by corresponding gradations in the amount of iron present. Eolkin² developed a method of measuring very small changes of gas pressure, such as those that occur in a container when small quantities of air diffuse through the gasket. The extensive studies of van Amerongen⁷ and others on the permeability, diffusivity, and solubility of gases in rubber have pointed the way to the elimination of the discoloration trouble in glass containers through the substitution of rubbers of low gas permeability, such as butadiene-acrylonitrile polymers and isoprene (methylbutadiene)-acrylonitrile copolymers, for GR-S type rubbers, which were used for gaskets until recently.

An effect on the color of food, corresponding to that occurring in glass containers, is not apparent in cans—perhaps because of the relatively small cross sectional area of the gasket after it is compressed and tightly confined in the double seam. Other factors that might contribute to the prevention of the passage of air through a double seam are (1) relatively large areas of compressed metal-to-metal contact in the double seam, which probably retard the gaining of access of air to the gasket and (2) increased energy of activation for diffusion in the rubber, which might result from high compression of the rubber in the double seam.

For frozen foods, since oxygen accelerates enzyme action, and for dehydrated foods, since both oxygen and moisture accelerate this action, there is a growing practice of using containers that protect the foods from these factors. Protection provided for these foods is now almost universally equal at least to that provided by a metal foil laminate and the use of hermetically sealed cans and jars is growing rapidly.

Interest also is growing in the practice of in-package desiccation of dehydrated foods, where the dehydration of the food is continued after the package is sealed, through absorption of moisture by a desiccant placed in the package. Moisture resistant packages must also be used to prevent loss of moisture by foods of comparatively low moisture content, in which a certain minimum of moisture is necessary for the preservation of quality. Examples are unpopped pop-corn and dried fruits. For popcorn, sealed cans are used; for dried fruits, foil laminates and other materials of comparable protective ability are used.

The custom is growing of obtaining double protection by enclosing from two to six small fiber or plastic packages of food in a single wrapper made of the same material as that used in the smaller packages. Materials frequently used for such packages are polyethylene film and metal foil laminates.

Consumer Acceptance Factor No. 10—Physical Characteristics of Outside Surface, Including Appearance. The outside surface of a retail food container needs to please two senses, sight and touch. To the touch, it should not give the impression of being greasy or sticky and, to the sight, it should be attractive. The attractive package on the supermarket shelf gets preferential attention of the family buyer. Label designs printed with fluorescent ink, which glows when illuminated by black light, are not uncommon and food manufacturing and marketing companies have designers constantly at work improving the coloring and the designs of their labels. Under Basic Factor No. 4, the outside surface of the container was mentioned in association with the container manufacturer and food packer's problems involving the inside surface. Protection of the outside surfaces of metal containers from rust is necessary, not only from the standpoint of preserving the food, but also from that of pleasing the consumer. A chemical treatment of untinned steel plate to prevent rust has become strikingly more effective, even within the past year or two, than it was previously and, where soldering is not necessary, chemically treated plate can be used in containers with assurance that outside rust will not be a problem even though the surface is not protected by organic coatings or lithography.

Consumer Acceptance Factor No. 11—Ease of Disposal. In these days of regular garbage and trash collections in cities, both large and small, the disposal of empty food containers in the home presents little difficulty. It continues to be true, however, that the most easily disposed of container is the one that can be burned. These include wood, fiber, and most plastic containers. Tin-plate containers rust away in time; glass containers never disintegrate except by being ground to bits.

Consumer Acceptance Factor No. 12—Special Features Related to Performance for Consumer. Certain features of a container, intended for one purpose, may increase its usefulness to the consumer in some quite unrelated respect. For instance, a durable reclosure on a glass or metal container makes the container permanently useful in the home; or the rigidity or special shape of a container may enable it to withstand rough handling in shipment, or make it adaptable to dispensing in a vending machine, thereby increasing its convenience to the consumer.

Final Step in Container Evaluation.

To illustrate the final step in the process of evaluating containers in the manner proposed in the preceding pages, a tabulation of grades under the different factors is presented in Table 22-13 for six container variations taken from a group of about 60 which were included in a study that resulted in the selection of container No. 30. It is noted that, on consumer acceptance alone, container No. 55 has the highest rating and, in the category of basic factors alone, container No. 43 has the highest rating.

TABLE 22-13. GRADES OF SIX TYPES OF CONTAINERS, INCLUDING THAT HAVING THE HIGHEST RATING

		Grades																			
		Basic factors						Consumer acceptance factors													
		1	2	3	4	5	6	1	2	3	4	5	6	7	8	9	10	11			
Code	Cost/M.	Ideal grade																			Totals
		30	20	10	10	5	5	3	3	3	3	3	2	2	2	2	3/4	1/2	1/2	1/4	
6	\$11.66	25.0	18	5	7	3 1/2	2 7/8	2	2	2 1/2	3/8	2	1 1/4	0	1/4	0	1/4	0	1/4	72.00	
17	13.33	20.0	17	6	8	3 1/2	2 1/2	2	1 1/2	3	7/8	1	1 1/4	0	1/4	0	1/4	0	1/4	67.12	
25	10.50	28.5	10 1/2	7	6 1/2	1	1	1	0	2	1 7/8	1 1/2	1	0	1/4	0	1/4	1/8	0	61.24	
30	10.85	27.4	18 1/2	8 1/2	7 1/2	2 1/4	2 7/8	2	2 1/2	2	1	2	1 1/4	1/4	1/4	0	1/4	0	1/4	78.52	
43	9.65	31.0	18	7	7 1/2	2	3	1 3/4	2 1/4	2 1/2	1 1/8	1	1 1/2	0	1/4	1/4	0	0	0	78.12	
55	11.11	26.7	17	7 1/2	8	2	3	2	2 3/4	2	3	1 1/2	3/4	1/4	1/4	0	1/4	0	1/4	75.95	

Summary

A study of the history and statistics of the development of food packages reveal that the technical advances of the 20th century have produced a phenomenal rate of progress which is constantly accelerating. The progress of the last 20 years, in particular, has been startling.

A method of evaluating different types of containers in respect to their relative over-all qualities or merits in a given application of food packaging is presented. All steps in the system of evaluating the containers are described and illustrated, including the final step of recapitulating the results of the study and making the final selection.

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23. FOOD QUALITY AND QUALITY CONTROL

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Definition and Limitation

Quality of foods may be defined as the composite of those characteristics that differentiate individual units of a product, and have significance in determining the degree of acceptability of that unit by the user. Thus the over-all quality of a food product may be broken down into its component characteristics, each of which may be measured and therefore controlled independently. Whenever any function is performed on a food item which differentiates it from the mass of the product, something has been done to its quality. At the same time the work involved has added to the cost of the product. It must then be determined whether the buyer of the product is willing to pay the additional cost¹.

The discussion in this chapter may be further limited to quality factors of primarily esthetic nature, such as those that are evaluated by the human senses of vision, feel, taste, and smell. Other characteristics, which may affect the degree of acceptability of a food item such as nutritive value, or wholesomeness are discussed in other chapters.

Quality is commonly thought of as degree of excellence. In a broader sense, however, it may be considered as a specification, or set of specifications, which are to be met within given tolerances, or limits. Thus the level, or the excellence of the product may be considered as the average, or mean level of quality, while the uniformity of the product may be described in terms of minimum limits, or more commonly, upper and lower control limits.

MEASUREMENT OF QUALITY

Quality characteristics may be measured objectively, that is by physical or chemical procedures, or more subjectively by means of sensory evalua-

tion of one or more human observers. It must be recognized that by and large, these factors of quality are being measured by sensory evaluation. Although isolated developments of methods for the objective measurement of quality have been in progress for several decades, it is only very recently that these methods could be organized as a new discipline and recognized as such.

Two principles are involved in any type of measurement; namely, precision and accuracy, where precision is the ability to duplicate results, with one instrument or with different individual units of the same instrument, while accuracy refers to the degree to which the instrument or procedure reflects human evaluation. Precision may be measured statistically by the coefficient of variability, and accuracy may be measured statistically by the coefficient of correlation, where objective values are correlated with human evaluation in the form of a testing panel of judges². Ordinarily greater precision tends towards greater accuracy, although that is not always true.

It is obvious that the main advantage in objective methods lies in the potential improvement in precision or duplicability. Thus an instrument or chemical procedure is more likely to provide identical results for identical samples of food, under conditions which might affect the precision of a human judge, such as lapse of time, differences among individual judges, and the state of health and discriminatory ability of the judge, etc. Less advantage may be expected for the objective method in terms of improved accuracy, since the accuracy of the objective method as such is measured in terms of agreement with human evaluation, except in the sense that the evaluation of one particular judge may not necessarily be in close agreement with human evaluation as a whole. One additional advantage is inherent in the objective method which is the automatic elimination of the human element, thus providing unbiased values, whereas human evaluation is always, whether consciously or not, subject to bias³.

Since the over-all quality of foods has been defined as a combination of distinct characteristics, which may not necessarily be all positively correlated to each other, it is necessary to employ some system such as is used by the Agricultural Marketing Service of the United States Department of Agriculture where each quality factor is carefully defined and evaluated separately. These have been grouped into three general categories, as shown in Table 23-1.

Appearance Factors

Factors of quality included in this group are those which the consumer evaluates with the eye; hence, they are the first to confront the consumer. It is usually on the basis of the impression gained from the appearance of

the product alone that it is accepted or rejected. Since this decision is made before the consumer has the opportunity of preparing the food for consumption, these appearance factors are therefore undoubtedly most important in the case of the first purchase, whereas other factors may be more important for repeat purchases. In the case of packaged foods, the container and especially the label are extremely important in their contribution to the appearance of the product.

Size, Shape, Pattern. Other factors that may be included in the appearance category are such items as size, shape, pattern, and wholeness, most of which may be measured easily by relatively simple devices such as scales, screens, micrometers, planimeters, sedimentation tests, or displacement in liquid media.

Defects. Various kinds of defects also fall in this category. Although they are also usually rather easily determined, (as in the case of number of split skins in frozen peas, or unsnipped ends of green beans), they occasionally present more difficult problems, usually qualitative rather than quantitative. Thus it is difficult to determine, for example, whether a particular discolored spot is dark enough or large enough to be called a blemish, or whether two small light spots are only as unacceptable as one darker or larger spot. Attempting to establish limits for such minutely detailed factors may result in unwieldy and lengthy procedures and specifications.

Another approach is through the employment of photographs, models, and drawings such as those being used and developed by the standardization division of the Production and Marketing Administration as visual aids in grading for defects, blemishes, and "character" factors⁴.

Gloss. This characteristic has been almost entirely overlooked in the objective evaluation of foods, although it is obvious that this factor which is usually termed finish in apples, and shine, or polish in other products is an evident and important factor of appearance in many food products. It is entirely possible that even one lot of peas may appear more desirable than another because of a difference in gloss. This factor is being measured in the paint industry by the goniophotometer, and the gloss meter. Thus the instruments in their present or modified form are available which are capable of measuring the gloss factor⁵. However, the work of applying these instruments to the measurements of the gloss factor in specific foods remains to be done.

Color. The objective measurement of color in foods has received considerable attention. Reference is frequently made to color dictionaries which usually are not entirely satisfactory because of the difficulty of matching color, and also because differences in color evident to the human eye are frequently smaller than the spacings found in color dictionaries. The Munsell system of color notations has been used with greater success, especially

TABLE 23-1. CLASSIFICATION OF QUALITY FACTORS AND THEIR MEASUREMENTS
Descriptive terms used for different products

	Bakery	Dairy	Eggs	Fish	Fruits
Appearance factors					
Size	Weight, volume	Weight, volume	Weight	Weight, drained weight	Diameter, drained weight
Shape	Symmetry	Uniformity	Normal		Height/width
Wholeness	Crumbling	Cell structure	Broken leakers	Texture	Cracked pieces
Pattern	Cell structure	Finish and appearance			
Finish	Finishing	Color			Finish, gloss
Color	Evenness	Sediment	Color, stained	Color	Color
Defects	Tunneling		Dirtyies, stained clots, spots, extraneous matter		Blemishes; bruises, spots, extraneous matter
Consistency	Consistency	Solids	Firm, weak		Consistency
Kinesthetic factors	Break, shred, compressibility, lightness, texture, mastication	Body texture, melting quality		Texture, fiber, decomposition	Texture, firmness, grit, character
Odor and flavor factors	Taste, aroma	Flavor, salt	Odor, palatability	Odor, off-flavor	Flavor, aroma, ripeness
	Meats	Poultry	Vegetables	Objective methods	
Appearance factors					
Size	Weight	Weight	Sieve size, drained weight	Scales, screens, micrometers	
Shape	Confirmation	Confirmation	Straightness	Dimension ratios, displacement, angles	
Wholeness	Torn, broken	Torn, broken	Cracked, pieces	Counts, % whole, photographs, models	

Pattern	Grain, marbling	Fleshing, fat covering	Color	Goniophotometer, gloss meters
Finish	Finish, condition	Finish	Color	Color cards, dictionaries, reflectance and transmittance meters
Color	Color	Color	Color	Photographs, drawings, models
Defects		Blemishes, bruises	Blemishes, spots, bruises, extraneous matter	
Consistency			Consistency	Consistometers, viscosimeters, Amylograph, farinograph
Kinesthetic factors	Texture, firmness, tenderness	Juiciness, tenderness	Texture, mealiness, succulence, fiber, maturity	Tenderometers, texturemeters, compressing, penetrating, cutting instruments. Solids, moisture, grit, fiber, tests
Odor and flavor factors	Odor, flavor	Odor, flavor	Flavor, sweetness	Hydrometers, refractometers, pH meters. Sugar, sodium chloride, acid, sugar/acid ratio, enzymes, volatile substances, amines

when used with a disk colorimeter when the angle and intensity of the light source were controlled, and the lens rotated instead of the color discs which were left stationary so that the proportion of the different color discs could be changed while the instrument was in action, thus making it possible to match colors in a relatively short time. Such instruments were manufactured in limited numbers by Keuffel and Esser, and Bausch and Lomb. Unfortunately both firms decided that these instruments were not profitable to manufacture, so that no satisfactory disc colorimeter is now available. Furthermore, the disc method is not entirely objective, since the matching of the color is done by the eye⁶.

With the development of photoelectric colorimeters and spectrophotometers, abridged spectrophotometric methods of color measurement were suggested involving the extraction of the plant pigments and the measurement of their concentration at specific wave lengths⁷. These methods are generally satisfactory to the extent that the color impression of a particular food is correlated with the concentration of the particular pigment that is extracted. The obvious limitations of the abridged spectrophotometric methods are that the color as seen by the eye may not necessarily be closely related to the concentration of the extracted pigment, and that the internal coloration of the product might be unduly overemphasized, since it is often the outer surface of the product that is responsible for the color impressions. More recently several photoelectric instruments have become available which are capable of measuring reflected light in terms of tristimulus colorimetry, so that results obtained with these instruments may be calculated in terms of a standard observer. Psychologically, these terms are value, or the lightness or darkness of the color; hue, or the dominant wave length, i.e., whether the color is yellow or orange, etc.; and chroma, or the intensity of the color.

The most basic of these instruments, and by far the most expensive is the Hardy spectrophotometer, equipped with a tri-stimulus integrator. Another instrument which is much less expensive, and more practical but which is still unusually precise, is the Hunter color-difference meter. A third, and still less expensive instrument is the Photovolt reflectometer, which however, is less automatic and not as precise.

Since results with tristimulus color meters are obtained as three distinct values, they are frequently difficult to explain unless they are converted into single color values. This can be accomplished by the use of multiple regression equations, and for practical purposes, charts or nomographs may be employed, where the discreet tri-stimulus values may be located and the color value read directly without calculation⁸.

Besides providing a value for the color factor as such, a color or pigment determination may occasionally provide information on other quality char-

acteristics, as for example greenness of peaches and apricots is closely associated with their ripeness and per cent whites in lima beans is associated with the stage of maturity.

Consistency. The consistency, or viscosity of a food may be an appearance characteristic, as it is in the case of cream-style corn⁹, or a means of evaluating future performance, as in the case of bakery products¹⁰. It may be measured by a variety of consistometers or viscosimeters, with certain specific instruments appearing to be more suitable for particular food items.

Kinesthetic Factors

Factors of quality included in this group are those which the consumer evaluates with his sense of feel. Since most processed products are not hand felt, these characteristics are largely determined by mouth feel and included such factors as tenderness or hardness, chewiness, juiciness, grittiness, and fibrousness. In general, these factors lend themselves readily to objective measurement by the use of mechanical instruments. Thus a considerable array of tenderometers, texturemeters, puncturemeters, succulometers, fibrometers, and pressure testers are available. These instruments vary in their precision as well as in their accuracy. Considering the tremendous variability encountered in food materials because of differences in varieties, growing conditions, and soils, these instruments frequently require special calibration for use with different varieties, and perhaps in different geographical locations¹¹.

In spite of the large array of instruments that have been developed for the purpose of measuring these kinesthetic factors, actually there are only a few basic principles involved. These are: (1) shearing force-pressure, which simulates the resistance offered by the food to the crushing action of the teeth; (2) shearing, or cutting force alone, which simulates the resistance of differentiated portions of the food such as fiber strands, to chewing; and (3) succulence, which simulates the amount of juice that is squeezed out of the food during mastication. All these measurements require the application of force; hence, it is logical to assume that all such kinesthetic measurements can be accomplished with one power unit in the same way that all color measurements may be made with one color instrument. One such multipurpose instrument is the shear press¹². Three different test cell assemblies may be provided for use with the same power unit, to accomplish the three different types of testing. Thus, one test cell, similar in design to the pea tenderometer, may be used to measure hardness or firmness of such different products as peas, lima beans, sliced apples, tomatoes, cherries, strawberries, or sweet potatoes. Of course, the range of values for lima beans will be many times higher than for strawberries;

however, both may be tested with the same instrument and test cell, but with the use of gauges of different ranges. Another test cell similar in design to the asparagus fibrometer, may be used for measuring the fibrousness of such commodities as asparagus, green beans, and celery, while a third test cell, similar in design to the succulometer, may be used to test the succulence of sweet corn, apples, or potatoes.

Quantitative, empirical, physicochemical methods may also be used successfully for measuring these kinesthetic factors, but the empirical procedure must be adhered to rigidly if precise results are desired. Examples of such procedures are the alcohol insoluble solids test for peas and corn, the fiber test for green beans¹³.

Flavor Factors

Factors of quality included in this group are those which the consumer evaluates with his sense of taste and smell. In contrast to appearance and kinesthetic factors, these flavor factors are difficult to evaluate objectively. In fact, it has been suggested that since flavor is a physiological sensation, it is by definition subjective, and therefore, not subject to objective measurement. The degree of sweetness can be approximated by a sugar determination, or where possible more rapidly but still less accurately by a refractometer or hydrometer. Saltiness may be approximated by a determination of chloride or sodium content. Sourness may be measured by total acid determination, or by the use of a pH meter.

Some progress has been made on the detection of off flavors. Here the component that is determined is not usually responsible for the off flavor or odor, but merely associated with it. Thus, various enzyme activity determinations were suggested as indicators of off flavor resulting from under-blanching of frozen vegetables¹⁴. Estimation of volatile acids, amines¹⁵, and succinic acid¹⁶ have been suggested as indicators of off flavor in stored fruit and fish.

Rapid, practical methods for determining the essential flavoring constituents of foods have not been developed as yet. Whatever work was initiated was abandoned with no practical results. Some aids however, are available that reduce the hazard of purely subjective evaluation of flavors.

The Henderson-Crocker system of odor notation is helpful in this direction¹⁷. Much progress has been made in improving the design, precision, and interpretation of taste testing panels, so that these essentially subjective methods are somewhat more objective in that they are more precise and comparable.

Age, Maturity and Ripeness

With certain foods there may be a group of quality characteristics that are rather constantly associated, so that one measurement may be a satis-

factory index of the status of all the associated factors. Age, maturity and ripeness are such concepts. Although these terms have been used in various ways, they may be defined here, as the stage of development of the organism or that part of the organism that is used as food. Specifically age refers to animal products¹⁸, maturity is used for vegetables such as peas, beans, and corn, where an immature stage is desirable, while ripeness is used for fruits, such as peaches, apricots, or tomatoes, where a fully ripe condition is desirable¹⁹. Thus, for example when the tenderometer is used to determine the maturity of a given variety of peas, some indication is provided not only of the hardness of the peas, but also their size, color, sweetness, likelihood of bruising, gain or loss in size during blanching, and nutritive value. Similarly, if a spectrophotometric determination of the presence of green pigment is made for peaches, information is gained not only of the quantity of the underlying green color, but also of the firmness of the flesh, the sugar-acid ratio, and the ease of handling in plant, the concentration of the syrup required, and the probable fill in weight²⁰.

Sensory Measurements

It must be recognized that even with the substantial progress that has been made in the development of objective methods, the bulk of quality evaluation is still accomplished by sensory methods. In routine, quality control operations, this evaluation is in the hands of individual trained inspectors who may be official government graders, or company employees. Such individuals usually develop considerable precision, and are remarkably accurate considering that in many instances no reference samples or objective tools are available for their guidance.

It may be expected that such subjective evaluations by single persons, no matter how experienced and trained may fluctuate as the season progresses. It is frequently found that in the absence of fixed reference samples, or objective tools, the tendency is to score materials too critically when the average quality is exceptionally good, and too leniently when the general quality level is exceptionally poor.

Overruling of the quality inspector by a higher ranking officer usually tends to do more harm than good, since the overruling is done by someone less familiar with the quality evaluation process. It is better to refer such questionable results to a panel of sensory testers, or even to a larger consumer preference panel.

These sensory testing panels are frequently resorted to in research and developmental work, particularly for factors such as flavor which is difficult to evaluate by any other means. They may also be used in determining the accuracy of a newly proposed objective method²⁰. They can be a precise tool if: (a) properly designed; (b) care is taken in selection of judges;

(c) proper physical facilities are available, and (d) statistical analyses are used for interpreting the data.

Difference or Preference. There are two types of sensory panels, namely, the difference test and the preference test. In the former, the purpose is to distinguish differences in samples to as minute a degree as possible on the basis of intensities. For example, if the hardness of peas is to be evaluated, the difference panel will score the samples on the basis of degree of hardness entirely, without indicating which degree of hardness they prefer.

In the preference test, however, judges indicate personal preferences. Here, the individual judge will indicate his preference for a particular sample of peas. In this case, one judge may prefer relatively harder peas while another may prefer more tender ones. Both judges are correct, even though they differ in their choice of sample, since they are expressing an opinion of preference rather than difference.

These two types of tests may be combined into a difference-preference test where each judge first scores the peas in accordance with their degree of hardness but also indicates which sample he prefers.

In general, taste panels that are used as quality control, or laboratory instruments, are usually of the difference rather than the preference type while consumer-survey panels generally consist of the preference type²¹.

Setting Up the Panel. From the statistical standpoint it is essential that each judge's score be arrived at independently. Where the panel members discuss the samples and agree on a score, results can be analyzed statistically, but much precision is lost because individual scores are not available.

It is advantageous, although not at all essential, that judges be isolated in separate compartments. Facilities should be arranged in such manner that there is little or no communication between them. Such communications are not limited to verbal expressions, for they also include visual expressions, and other means of communicating approval or disapproval of particular samples. Samples may be offered either in a particular order determined in advance or completely at random.

Selection and Evaluation of Judges. For preference testing, judges should be selected entirely at random, except in the case of elaborate consumer surveys, where attention should be given to such factors as economical status, age, sex, race, and community size and location.

For difference or difference-preference testing, where the panel is to serve as an analytical tool, it is advantageous to have the most precise tool possible at minimum cost. For this purpose, judges should be selected on the basis of the following three criteria:

(1) How well can they detect differences—i.e., how small a difference can they detect? Obviously if a number of judges are available, each of

whom can detect every minute difference, they will be much more efficient than another, perhaps larger, group that cannot detect such small differences.

(2) How consistent are they—i.e., how well can they repeat themselves on duplicate samples?

(3) How do they compare to panel average? That is, are they inclined to score everything too high or too low? Except where actual grades are based on these panel scores, this criterion is of least importance, as long as the judges are consistent and show a high degree of discrimination.

Scoring. The simplest type of score would be one where the judge chooses one of two or more samples without assigning actual numerical values. Other score cards should include enough discreet units to allow the individual judge to use his maximum discriminatory ability. If, for example, canned samples are evaluated on a scale of 4, with 1 being equal to sub-standard, 2 to standard, 3 to extra-standard, and 4 to fancy, such a score card would reduce the amount of information that can be obtained from such a panel.

It would, therefore, seem preferable to use a score of 1 to 10, where 1 would be substandard; 2, 3, 4 would be equivalent to increasing quality levels in the standard range; 5, 6, 7 increasing quality levels in the extra-standard range; 8, 9, 10 increasing quality levels in the fancy range. On the other hand, if the judges are unable to distinguish more than four categories, the availability of a large number range may lead to confusion.

Paired Comparison. The simplest design for a taste test is a paired comparison test where each judge is asked to compare two samples only, and indicate whether they are different, or which sample is preferred. A variation of this method which is used commonly in the distillery industry is the presentation of sets of three samples, the first of which is always identified as the check. The judge is then required to indicate which of the other two samples are identical to the check sample.

Triangular Comparisons. Statistically the triangular tests are decidedly more efficient (by 50 per cent) than paired comparison tests. They may be handled in exactly the same manner—that is with every set consisting of three samples of which two are the same and one is different. However, one of the paired samples is not identified and instead of being told that he is to select the sample which is similar to the identified sample, the judge is asked to select the odd sample. Thus, his chances of selecting the right sample by chance alone are only 1 in 3, whereas in the paired comparison method, his chance is 1 in 2. The significance of the judge's results may be determined by reference to tables²².

Multiple Comparison. By this system, each judge is provided with sets containing an unlimited number of samples, and he is required to score each sample independently on the basis of some numerical scoring system.

The results may be analysed by the use of the analysis of variance, or some simplified modification thereof²³. Other methods based on ranking of the sets of samples are also available²⁴.

In general, the paired comparison method is used mainly in consumer survey studies, and the triangular and multiple comparison methods by professional testers. Where the product is homogeneous, such as an alcoholic beverage, the triangular method may yield satisfactory results, however, as the product tends to vary, and the discreet units increase in size, the multiple comparison method becomes increasingly more efficient.

WEIGHTING THE QUALITY FACTORS

After the separate quality factors are established, and measured adequately, they must be recombined into one single grade in order to determine the over-all quality of the product. Before this recombination occurs, it is first necessary to assign a relative weight to each factor of quality. This has been done by a number of different methods, as for example the relatively simple method used by the U.S. Department of Agriculture, or the more complex method suggested by Plank. However, the weighting in all these procedures is arrived at subjectively. Statistical methods are available where the relative weights to be assigned to different quality factors may be arrived at objectively. This can be done through the use of multiple correlation calculations where the individual factors or tests of quality may be correlated simultaneously with an overall grade. By utilizing such a procedure for green beans, it was found that maturity as measured by per cent seed accounted for 29 per cent of the total; fiber, as measured by the blend or fiber method, 27 per cent; color, as measured the concentration of the green pigment, 15 per cent; and flavor, as measured by a taste testing panel, 29 per cent²⁵.

APPLICATION OF MEASUREMENTS

Grades and Standards

These measurements, whether they be objective or sensory, may be used in the form of grades and standards of quality.

In general, the standards used in measuring the quality of agricultural products have been established by government or by independent agencies to facilitate marketing. Some standards are more widely used or accepted than others depending upon the nature of the standards and the purposes to be served.

The standards which now exist may be classified into three broad categories: government standards, trade standards, and research standards. *Government standards* include those issued by any federal, state, county or municipal agency. Examples of Federal standards of minimum quality

TABLE 23-2. TERMS USED FOR QUALITY GRADES

	Eggs	Fruits			Meats	Poultry		Vegetables		
Top grade	AA	U.S. 1	A	Fancy	Prime	U.S. 1	A	U.S. 1	A	Fancy
2nd grade	A	U.S. 2	B	Choice	Choice	U.S. 2	B	U.S. 2	B	Extra standard
3rd grade	B		C	Standard	Good	U.S. 3	C		C	Standard
Other	C	Culls		Substandard	Commercial Utility Cutter Canner			Culls		Substandard

of a mandatory nature are those promulgated under the Federal Food, Drug, and Cosmetic Act of 1938; examples of Federal standards setting forth different grades are those issued by the U.S. Department of Agriculture for various commodities. Many of the state, county, or municipal standards are identical with, or are modifications of federal standards; examples of minimum state standards are the Arizona, California, and Texas regulations governing the marketing of many principal fresh fruits and vegetables.

Government standards may be mandatory or voluntary (permissive). Mandatory standards are regulatory in nature. Voluntary standards become regulatory when they are adopted under certain legal provisions for specific uses such as the marketing agreements on certain dried fruits or fresh fruits in California.

U.S. Department of Agriculture standards have been promulgated at the request of, and in cooperation with, interested trade groups, such as growers, processors, packers, handlers, wholesalers and retailers. The point has been raised that the interest of such trade groups in the development of grade standards may not reflect consumers' preferences and that more consideration should be given to the needs and preferences of the ultimate consumers in developing grade standards.

Trade standards define expressed or implied grade levels of quality as established by individual or firms or trade associations. These may be written in such forms as contractual agreements or quality control specifications, or they may be unwritten understandings between interested parties. Examples of such standards are these established by the Institute of American Poultry Industries, or the Descriptive Labeling Program of the National Canners Association.

Research standards for measuring specific quality characteristics may be set up by research workers as a part of their investigations. These standards may or may not coincide with government or trade standards. To the extent that the measuring techniques developed prove to be objective and reliable measures and practical for a given purpose such as inspection, they may be adopted for official use. Such a research method may serve a

regulatory agency in determining compliance with legal provisions whether or not they are readily adaptable for field use in inspection.

To serve the intended purposes, standards for grades must meet the needs of both the trade and the user. To meet the needs of the trade, standards for grades must cover the entire range of quality found in the marketable product. They must separate the product into ranges of quality that will give sufficient differential in price to make grading economical. The quality attributes included should be measurable by simple, accurate, and practical methods.

To meet the needs of the user, standards for grades must be based upon those attributes that are most important in determining the acceptability of the product to the user. Different buyers, for example the wholesaler versus the consumer, may prefer different attributes. Standards should separate the products into qualities that will give differences in the degree of acceptability in proportion to the added expense.

Coordinated effort on the part of many groups will contribute to the revision and improvement of present grade standards and to the promulgation of new standards.

Quality control

Measures of quality may be used as tools in a quality control program not only to measure the finished product, but also to test the suitability of the raw materials and as indicators of performance during the manufacturing process.

Acceptance Sampling. Where the purpose of the test is to accept or reject a lot of material, an *attributes* sampling plan may be suitable. This plan merely indicates whether each unit tested is satisfactory, and the total lot is then accepted or rejected on the basis of the total number of defective units, depending on the size of the lot, and the acceptable quality level²⁶. Such systems are relatively easy to apply, require very little calculations. They are being used effectively particularly in the sampling of materials other than foods, such as car lots of cans, bottles, and glass tumblers.

Testing of the raw food material, however, cannot ordinarily be handled by attributes, since these tests are usually destructive and time consuming. Actual values are usually required for blending purposes, or adjustments in the process. The lot of raw material is rarely rejected, but the price is adjusted on the basis of the test values obtained. For all these reasons variables plans are the only practical solutions.

Sampling by Variables. Here, ready-made tables are not available, although they may be prepared for specific purposes. In addition to the information required for setting up an attributes plan, it is necessary to know, in advance, the anticipated variability within the lots of the material to be inspected²⁷.

This variability is usually expressed by a statistic known as the standard deviation, usually symbolized by the Greek letter sigma (σ). Thus an average value (X) plus or minus (\pm) the standard deviation (σ)—($X \pm \sigma$)—means that approximately two-thirds of the individual samplings will fall within one standard deviation, above or below the average value, and about 95 per cent, or 19 out of 20 individual samplings, will fall within two sigmas (i.e., standard deviations) of the mean²⁸.

The problem of sampling is further complicated by the fact that much of the raw material reaches the processor in containers such as baskets crates, etc. The present practice is to remove a given number of containers, and test all the material in these containers. For example, in the sampling of truck loads of tomatoes containing 500 to 1000 baskets, it is common practice to remove about three baskets and utilize all the 300 to 400 fruits in the test of quality. It was easily demonstrated that such a sample was inadequate; however, the use of a much larger sample of 10 or 12 baskets containing well over 1000 fruits was prohibitive. There remained the possibility that an adequate sample may be drawn from more than three baskets, but only a fraction of the tomatoes in each basket would be used for the quality determination. Since it may be assumed that the sampling error will be reduced as the number of baskets from which the sample is drawn is increased, and the cost will increase as more baskets are handled, the problem is to determine at what point does the cost of handling additional baskets begin to outweigh the reduction in sampling error.

This problem was solved by comparing a variety of sampling plans where 100 fruits were removed from different numbers of baskets. The standard error for each sampling plan was calculated, and the cost in terms of minutes of labor estimated. The number of replications required to reduce all the plans to a similar per cent error term was calculated, and this number multiplied by the respective cost term provided an "efficiency index" which indicated that the removal of ten tomatoes from each basket was the most efficient sampling method. Considering the risks involved in the size of the sampling error, and the sampling costs, a plan was evolved for sampling loads of different sizes²⁹.

In-Plant Control. A similar procedure, based on the calculation of the standard deviation, may be used to establish limits for a quality control chart. These upper and lower limits are ordinarily set at three sigmas—i.e., the upper control limit is set at the mean plus three times the standard deviation, and the lower control limit is set at the mean minus three times the standard deviation. This would indicate to the processor that as long as the usual good job is done, over 99 per cent of his check samples should fall within the limits³⁰.

It is generally recognized that food materials are more variable than other manufactured articles. This in itself does not limit the usefulness

of control charts for food processing lines. It merely indicates that control limits must be wide. At the same time it provides excellent opportunities for reducing variability and eventually producing a more uniform product.

A more serious problem is the fact that production schedules and the proportion of the production within any given quality bracket may vary primarily as a result of weather conditions.

Since such situations occur rather frequently, it is suggested that some control charts in food plants may be based entirely on grade specifications merely for the purpose of having a continuous chart of the grade of the product as it is being manufactured.

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24. DISPOSAL OF FOOD PLANT WASTES

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Two general types of wastes are produced by food plants—liquid and solid. Liquid wastes originate from (1) cleaning and washing food products, (2) processes in which water has a functional use as a means of hydraulic transportation, extraction, cooling, etc., (3) spillage or wastage of liquid foods or ingredients, (4) concentrates, (5) condensates, and (6) equipment and floor washing. Solid wastes originate either from the food material itself (rejects, trimmings, inedible parts, adhering soil) or residues from unit operations (extractions, stockyard manures, etc.). Conversion of certain solid wastes to usable by-products may be economically feasible (meat and poultry packing, citrus peels, beet sugar pulp, etc.). Except in a few cases the concentration of soluble organic materials in liquid wastes does not warrant by-product recovery. The disposal of the liquid portion of food plant wastes presents the greater problem.

Discharge of liquid food plant wastes directly to a stream or other receiving body of water seldom is feasible. The presence of excessive amounts of dissolved or colloidal food materials may stimulate the growth of aerobic aquatic bacteria to the point where adverse stream conditions develop through a reduction of dissolved oxygen. The normal growth and reproduction of fish may be impaired or fish may die of suffocation. The complete depletion of dissolved oxygen leads to a septic condition with the evolution of foul odors. Liquid wastes may carry in suspension finely divided solid particles which may settle out and destroy desirable organisms living within or on the bottom of streams or lakes, may destroy spawning beds or may accumulate as objectionable sludge deposits or as surface scums.

Dissolved, colloidal and suspended organic substances constitute the

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major pollution hazards from food manufacturing plants. Certain food industries or processes may yield soil, grease, lime cake, lye wastes, etc., as special pollutants. In the following sections the principal methods of treatment and disposal of wastes from the canning, freezing, dairy, meat, poultry, beet sugar, and miscellaneous food industries are discussed. For more detailed information recourse should be had to the American Chemical Society Monograph No. 118, "Industrial Wastes, Their Disposal and Treatment" (Reinhold Publishing Corp., 1953) and to the selected literature references at the end of each section. Often additional unpublished information of value can be obtained at Agricultural Experiment Stations, the Sanitary Engineering Departments of the several State Boards of Health or Water Pollution Control Agencies, and from the research departments of industry trade associations. For information on analytical procedure for the examination of wastes reference should be made to the current edition of 'Standard Methods for the Examination of Water and Sewage' (American Public Health Association).

Frequent reference will be made to BOD, the abbreviation for biochemical oxygen demand. This is one of the most significant indicators of the strength of food wastes in relation to water pollution and of the efficiencies of treatment processes. Biochemical oxygen demand may be defined as that quantity of oxygen expressed in terms of parts per million which is utilized by aerobic biological organisms in the stabilization of decomposable organic matter during a stated time at a given temperature. A time of 5 days at 20°C is generally employed and understood unless otherwise stated. Under these conditions approximately 68 per cent of the organic matter has been stabilized.

A second widely used indicator of the character of a waste both before and after treatment is the suspended solid content of the waste. Suspended solids are those solids, organic or inorganic, which are physically suspended in the waste. Organic suspended solids contribute to the BOD of the waste, but their greatest significance lies in the possibility that the discharge of suspended solids may create objectionable sludge deposits in streams or lakes. Data on suspended solids are necessary for a consideration of certain types of treatment and as one test for treatment plant efficiency.

Other indicators which may be required are volatile suspended solids, total solids, dissolved solids, pH, turbidity, color, toxicity, oil and grease, taste, presence of odor producing substances, and temperature. An accurate knowledge of total and unit process waste discharges is essential.

The following discussion of food plant wastes must of necessity be abbreviated. Development of the subject has been primarily directed to those interested in the smaller or average size plant operations where plant personnel may do much to prevent or abate pollution with a minimum of out-

side assistance. The selection of the most suitable method of treatment and disposal, particularly, for certain large food processors, may be fraught with uncertainties and differences of opinion among qualified research workers and industrial sanitary engineers. Treatment facilities for large volumes of strong wastes may involve expenditures of very large sums of money. If costs are ignored any food plant waste can be treated to a degree satisfactory for any disposal situation. This, of course, is unrealistic. Successful treatment must be commensurate with the ability of the polluter to finance waste treatment.

Canning Wastes

The canning of fruits and vegetables necessitates the use of large quantities of water for produce washing, for the hydraulic transportation of the produce from one piece of equipment to the next, for the maintenance of equipment and factory sanitation, and for the cooling of the canned product after heat sterilization. Except for the latter, these waste waters consist essentially of carbohydrates in solution and suspension together with discrete particles of the products being canned, ranging upward in size, in some cases, to that of the raw food product. Can cooling water almost always contains little or no organic matter. It is logical, therefore, to segregate and to separately dispose of this innocuous waste water to storm sewer or stream. Where waste treatment or disposal presents a problem, separate disposal of can cooling water is dictated by economic considerations. Since this is almost always the case further reference to liquid canning factory wastes implies the absence of can cooling water.

The adoption of measures in the plant whereby the strength of waste waters is held to a minimum may be the most economical method for the removal of part of its pollutorial strength. The most outstanding example is the segregation and separate disposal of pea and corn stack ensilage liquor. These wastes are relatively small in volume but their low pH and extremely high BOD (up to 78,000 ppm) have necessitated their removal from general factory wastes. A survey of wastes originating at unit operation may disclose other low-volume, high-BOD wastes that could be segregated advantageously for separate disposal. Suggested examples are sour cherry pitter drippage with a BOD of 38,000 to 70,000 ppm or citrus peel bin drippage with a BOD of approximately 50,000 ppm.

Other methods for the reduction in the strength of waste waters in line with the adage, "An ounce of prevention is worth a pound of cure," are the following:

- (1) Construction, maintenance and operation of equipment so as to prevent product spillage. Fruit and tomato juices and sugar sirups have particularly high BOD's.

(2) A program of good housekeeping to maintain floors free from spilled solid food material.

(3) Avoidance of practices which combine solid and liquid wastes. The admittance of solid wastes to factory floor drains increases the dissolved and suspended solids of waste waters and imposes an unnecessary burden on subsequent procedures for their removal.

The following practices should be avoided:

(a) Use of flumes to convey solid wastes to waste screening units. Solid wastes when small in volume can be handled in containers suitable to the type of waste involved. Large quantities can be removed by belt or screw conveyors.

(b) Dewatering of solids in presses or cyclones unless special provision has been made for the separate collection and disposal of the expressed liquor.

(c) Comminution of solid except for discharge to isolated lagoons where odors present no problem or as discussed under spray irrigation.

The foregoing considerations together with wide variations in water usage, water reuse, and canning procedures combine to produce marked differences in the quantity and characteristics of canning factory wastes even among canners of the same product. From this it follows that the waste strength and output of each plant must be separately determined, particularly when considering certain types of biological treatment. The volume, BOD, and suspended solids of a number of different cannery wastes are given in Table 24-1.

The disposal or treatment of liquid wastes from canning plants will depend upon an appraisal of the following data: volume and characteristics of each type of waste produced, degree of treatment required, possibility for segregation and separate treatment or disposal of low-volume, high-BOD wastes, area and topography of land available for treatment plant or disposal system, possibility of utilizing local municipal sewage treatment works if any exist or are contemplated, and financial considerations. In regard to the latter, consideration must be given to the fact that nearly all canning plants operate on a seasonal basis, hence are not in a position to justify a capital expenditure for treatment that could be borne by a plant operating throughout the year. After obtaining the above basic information, treatment by one or a combination of the following methods can be considered: screening, chemical precipitation, biological filtration, discharge to a municipal sewage treatment works, discharge to an impounding lagoon, or land absorption by one of the several different available methods.

The most economical method for the removal of the large solids in liquid wastes is by means of screening. Screening is a necessary treatment procedure and seldom can be dispensed with. Failure to screen or failure to oper-

TABLE 24-1. VOLUME, BOD AND SUSPENDED SOLIDS OF CANNERY WASTES

Product	Volume per case (Gal)	5-Day BOD (ppm)	Suspended solids (ppm)
Apples.....		1,680-5,530	300-600
Apricots.....	57-80	200-1,020	260
Asparagus.....	70	16-100	30-182
Beans, baked.....	35	925-1,440	225
Beans, green or wax.....	26-44	160-600	60-150
Beans, kidney.....	18-20	1,030-2,500	140
Beans, lima, dried.....	17-29	1,740-2,880	160-600
Beans, lima, fresh.....	50-257	190-450	420
Beets.....	27-70	1,580-7,600	740-2,220
Carrots.....	23	520-3,030	1,830
Corn, cream style.....	24-29	620-2,900	300-675
Corn, whole kernel.....	25-70	1,120-6,300	300-4,000
Cherries, sour.....	12-40	700-2,100	20-605
Cranberries.....	4	2,250	105
Grapefruit.....	5-56	310-2,000	170-285
Mushrooms.....	6,600*	76-850	50-240
Peaches.....	1,300-2,600*	1,350-2,440	600
Peas.....	14-75	380-4,700	270-400
Peppers.....		600-1,220	
Potatoes, sweet.....	82	1,500-5,600	400-2,500
Potatoes, white.....		200-2,900	990-1,180
Pumpkin.....	20-50	1,500-6,880	785-1,960
Sauerkraut.....	3-18	1,400-6,300	60-630
Spinach.....	160	280-730	90-580
Squash.....	20	4,000-11,000	3,000
Tomatoes.....	3-100	180-4,000	140-2,000

* Per ton.

ate screening units properly has led to the following difficulties: (1) complaints due to the presence of wastes in receiving bodies of water large enough to handle the soluble organic matter but not floating solids or those which settle and form sludge deposits, (2) overloading of municipal treatment plants, (3) clogging of biological filter distribution nozzles, (4) overloading of impounding lagoons, requiring odor control, and (5) impairment of the operation of spray irrigation sprinklers.

Rotary or vibrating mechanically operated screening units are commercially available. The former require less mechanical attention. The service life of the wire cloth on vibrating units is apt to be less but these units are capable of handling greater volumes of waste per square foot of screen cloth and discharge screenings in a drier condition. Stainless steel screen cloth is always used on vibrating screening units. Copper or bronze screen cloth is usually used with rotary screens unless the wastes are particularly corrosive. It is impractical to use wire cloth finer than 40-mesh and even this size will present difficulties with certain types of wastes such as tomato waste.

A 20-mesh screen is considered more practical and is permitted by many pollution enforcement agencies. Under special circumstances screens with larger openings can be used to advantage. Screening through a 10-mesh screen or one with openings as large as $\frac{1}{16}$ -inch may be suitable when final disposal is made through spray irrigation, to large rapidly flowing streams, ocean disposal, or to municipal plants handling a large volume of sewage in comparison with the factory flow. Screening is a relatively simple operation but one of great importance.

Chemical coagulants may be used to further reduce the strength of screened wastes. Lime followed by either ferrous sulfate or alum is generally used. When properly conducted, chemical treatment will remove suspended and colloidal solids but not such materials as sugars which are in true solution. The degree of treatment, therefore, will depend upon the relative proportion of BOD associated with the suspended and colloidal solids to the BOD of the soluble organic solids. This ratio will vary with individual wastes. Pea, corn and tomato wastes, for example, may be expected to yield a 50 per cent BOD reduction by chemical precipitation under average commercial operating conditions. On the other hand, fruit wastes with BOD's due largely to sugars may respond to chemical precipitation by a reduction of only 25 per cent or less. Treatment by chemical precipitation may be indicated when (1) the receiving stream or other body of water is capable of assimilating the residual BOD of the waste, (2) removal of suspended solids is of primary consideration, and (3) pretreatment prior to discharge to a municipal sewage plant is required.

Two types of chemical treatment plants are in use, the continuous-flow and the fill-and-draw or batch treatment. Lack of flexibility in maintaining optimum chemical dosage rates to conform to frequent fluctuations in waste characteristics, and the inability to remove completely the large volume of sludge produced, limit the efficiency of continuous-flow systems to certain types of operations. For the small or average sized canner operating on a seasonal basis the fill-and-draw system is more suitable. Briefly, this method involves pumping screened waste to one of several treatment tanks where the coagulants are added and flocculation obtained. The operator is able to judge by appearance whether additional coagulants are required. The floc is allowed to settle, carrying down with it the suspended and colloidal solids of the waste. The clear supernatant liquid is discharged through a floating pipe. Sludge, which may amount to some 10 to 15 per cent by volume of the waste treated, is discharged by gravity to specially constructed sludge drying beds. While waste is being treated, settled and discharged in one tank, the flow of raw waste is diverted to another tank. A complete system consists of at least two treatment tanks.

Treatment of domestic sewage and certain industrial wastes on biological

filters is a standard practice and much experimental work has been done toward its application to cannery wastes. It has been shown that cannery wastes are amenable to treatment on either conventional or high-rate biological filters providing adjustment is made for the mineral nutrient deficiency, particularly nitrogen, which characterizes many fruit and vegetable wastes. Treatment by biological filtration has one very serious handicap in-so-far as its application to seasonal canners is concerned. The efficiency of a biological filter depends upon the development of complex biological growths on the surfaces of the rock or other medium which constitute the filter. The development of these growths to a satisfactory state of efficiency requires the application of wastes for a period of several weeks and continuous application thereafter. Obviously these conditions cannot be fulfilled by the seasonal canner with a short and intermittent operation. For the nonseasonal canner or for continuous operations which extend over a substantial portion of the year biological filtration may provide the only feasible type of treatment despite the relatively high construction costs involved.

The treatment of food wastes at municipal sewage treatment works is an ideal solution when the city plant has sufficient capacity to handle the added waste volume and organic loading and further provided that the charges, if any, for the acceptance of the food wastes are not exorbitant. With respect to the latter, the present trend is to charge for industrial wastes on the basis of: (1) volume, (2) pounds of BOD in excess of that normal to domestic sewage, and (3) suspended solids in excess of that normal to domestic sewage. A reduction in the volume of waste frequently can be achieved by the elimination of practices resulting in water wastage or by a process alteration involving water reuse. If the suggestions previously given relating to good housekeeping, avoidance of product spillage and elimination of the several undesirable practices which permit solid wastes to enter factory waste drains are observed a direct savings in charges for both excess BOD and suspended solids will be achieved. Where these charges are in effect the most effective mechanical screening must be utilized. Further reductions by chemical precipitation may be indicated. An equalization of the flow of wastes over a 24-hour period may be necessary to relieve the load on the municipal treatment plant. The retention of cannery or other food wastes in long or slow-flowing municipal sewer systems may produce odors or create acid conditions. Chlorination of the wastes immediately before entering the sewer should correct these conditions. Wastes which are initially acid, e.g., fruit wastes, may require neutralization or alkalization to a degree which will insure their arrival at the treatment plant in an acceptable condition. Cannery wastes are being treated successfully in municipal treatment plants of both the biological filtration and activated sludge types.

The disposal of cannery wastes in lagoons or by one of the several land absorption methods has the important advantage that when properly conducted stream pollution problems are completely avoided. The possibility of polluting underground water must be evaluated before undertaking any form of land disposal. The impounding of wastes in lagoons has been an important method of disposal for over a decade. Early attempts to utilize lagoons were not successful because of the odors produced. It is seldom possible to secure a lagoon site so isolated that odors create no problem. Lime, chlorinated lime, sodium hydroxide, oil, and disinfectants have not proved to be successful odor control agents.

Introduction of the use of sodium nitrate (fertilizer grade) for odor control led to a rapid expansion in the use of impounding lagoons. Objectionable odors are not produced under aerobic conditions. The oxygen contained in the nitrate radical is available for aerobic bacterial utilization. Nitrogen derived from the nitrate radical compensates for any nitrogen deficiency of the waste thereby accelerating the rate of biological stabilization. The available nitrogen also stimulates the growth of chlorophyllaceous organisms which under the influence of sunlight evolve oxygen. Thus sodium nitrate both directly and indirectly provides for aerobic stabilization. The cost of sodium nitrate prevents its addition in an amount sufficient to satisfy the entire oxygen demand of the waste. Odor control rather than odor elimination is therefore practiced.

A number of factors influence the course of biological stabilization making difficult the calculation of the sodium nitrate dosage required for odor control. As a practical procedure it is recommended that 200 pounds of sodium nitrate be added on a trial basis to screened beet, carrot, corn, pea or tomato wastes per 1,000 standard cases packed. If additional odor control becomes necessary more sodium nitrate must be added.

It is important that wastes be thoroughly screened before admittance to the lagoon, to reduce the biological oxygen demand. Because of the extreme oxygen demand of the seepage from pea and corn ensilage stacks this seepage must never be admitted to lagoons requiring odor control. Large shallow lagoons are recommended to provide for maximum natural aeration and because the stimulating effect of sunlight on chlorophyllaceous organisms is effective on a greater proportion of waste.

One single large lagoon capable of holding the entire waste discharge from a season's canning operation is customarily used. In addition, the capacity of the lagoon should be large enough to permit the retention of 25 per cent of carry-over from one season to the next. The presence of this quantity of stabilized carry-over markedly assists in the subsequent stabilization of fresh wastes and provides a blanket of water over the bottom of the lagoon effectively preventing luxuriant growth of weeds during

periods when the lagoon otherwise would be dry. Weeds provide quiescent mosquito breeding areas, collect and retain scum, reduce atmospheric reaeration, and when finally water-killed contribute decomposable organic matter.

The BOD of a properly operated sodium nitrate treated lagoon receiving pea and corn wastes for example should be 50 ppm or less by December. It is customary to retain the wastes until the following early Spring for further stabilization and to discharge at that time at a controlled rate when streams are at maximum flow.

There recently have been introduced on the market several odor masking preparations for use in lagoons. These materials appear to function solely by providing a pleasant odor which disguises the obnoxious odors associated with untreated lagoons. When used in sufficient quantity some of these materials achieve the desired objective. However, at least some odor masking preparations partially inhibit bacterial stabilization so that the period of odor production is extended long after canning is over. Retarded stabilization may seriously interfere with subsequent discharge to a stream. It is quite possible that a completely satisfactory odor masking agent may be developed.

There are three general types of disposal by soil absorption not counting those lagoons in which complete absorption may occur. These are: (1) absorption beds, (2) ridge and furrow irrigation fields, and (3) spray irrigation.

Absorption beds may be located in gravel deposits, or screened wastes may be flooded onto large shallow beds (broad irrigation). The conditions necessary for successful operation by broad irrigation are: (1) freedom from soil clogging solids in the waste, (2) availability of soil having a rapid water absorbing capacity so that absorption is completed within a few hours to avoid odor developments, (3) level ground so that waste may be applied evenly, and (4) sufficient bed capacity so that a system of rotation with drying-out periods can be maintained. Disposal by absorption beds has been rather limited.

Absorption by ridge and furrow irrigation also has been quite limited. A typical installation would provide for furrows approximately 2 to 3 feet wide at the top, 1 to 2 feet wide at the bottom and 1 to 1½ feet deep, constructed on contours to provide for flow of waste by gravity. Ridges between furrows are approximately 3 feet wide. Wastes are diverted from a header ditch into a group of furrows until full, then successively into other groups. By the time the cycle needs to be repeated the first groups are dry. The character of the soil must permit absorption before odors are produced. Ponding must be avoided. Growth of weeds assist in odor control by reducing wind sweep and also assist in the soil drying-out process by transpira-

tion. The topography of the irrigation area may require an embankment to exclude surface drainage.

The third system of land irrigation is disposal by spray irrigation. It is limited largely to application during nonfreezing weather but has been combined with lagooning of winter produced wastes. Disposal by spray irrigation has proved very successful and a large number of installations have been placed in operation since 1950. Extension to the disposal of other types of food plant wastes is in progress. Spray irrigation is an adaptation from the well-known method of watering agricultural crops using portable sprinkler systems. For waste disposal the system is comprised of the following units:

(1) The land on which to spray. Availability of land within economical pumping distance generally is the determining factor in considering disposal by spray irrigation. Several irrigation fields are located at a distance of a mile from the canning plant and in one case $3\frac{1}{2}$ miles.

(2) A vegetative cover crop to aid absorption and prevent erosion. This is of vital importance to a successful operation. Spraying onto bare soil or one with a sparse vegetative growth will provide for relatively poor waste absorption and result in erosion. The rate of water absorption may be increased several-fold by a cover crop because: (a) partial sealing off of the soil through the agency of rain-drop (waste) impact and soil classification is prevented, (b) infiltration into soil is augmented by plant roots, (c) the wetted area subject to evaporation is greatly increased, and (d) absorbed ground moisture is dissipated through plant transpiration. The choice of cover crop will depend upon geographical location and the use to which the irrigated area is put. The watering of agricultural crops such as peas, corn, and grains, while possible, have usually resulted in damage from overwatering. Spray irrigation of pastures or for the purpose of growing alfalfa or hay crops have provided excellent cover crops and consequently have found widespread application. Wooded areas also have been successfully used for spray irrigation.

(3) A mechanically operated screening unit. The removal of solids which otherwise would plug the sprinkler nozzles or interfere with pump operations must be achieved.

(4) A surge tank or pit. Screened wastes are collected in a surge tank to provide for proper operation of the high pressure pump. The surge tank usually is located at the plant, however, when the irrigation field is located at a distance screened wastes are pumped to a surge tank located at the field. The tank should be accessible for periodic cleaning and preferably of concrete construction. It should have a capacity of 15 to 30 minutes flow of waste when used in conjunction with a float-operated electric pump. Gasoline or diesel operated pumps require larger surge tanks because their

operation is manually controlled. The smallest practical sump is desirable in order that retention of the waste will not be so long as to produce septicity. The spraying of septic wastes liberates volatile odorous constituents whereas fresh wastes are odorless (sauerkraut waste an exception).

(5) Auxiliary stationary screen. The suction pipe or hose of the pump must be enclosed by a screen. Trash, leaves, or occasional solids by-passing the mechanically operated screen unit must be removed.

(6) High pressure pump. A centrifugal pump is required which can deliver wastes with a pressure of 35 to 100 pounds at the sprinklers. These pumps may be gasoline, diesel or electrically driven. Generally, electric motors which can be equipped with a safety line-pressure switch and operated by a float control are preferred.

(7) A main line. Depending upon local conditions the main line (two main lines if the surge pump is located at a distance from the plant) may be a permanent installation or may consist of portable agricultural pipe laid above ground and maintained in place only during the time when wastes are produced. Standard portable pipe is so constructed that when the line pressure drops to about 5 pounds water drains out unless special precautions are taken. Main lines must not leak wastes at any time.

(8) Lateral lines. Quick-coupling, self-draining, lightweight aluminum lines are used for laterals. The number of laterals and their size must be engineered to conform to the quantity of waste to be sprayed and the size, shape and contours of the irrigation area. The frequency with which laterals need to be moved from one position to the next will depend upon the permissible rate of water application.

(9) Sprinklers. Self-actuated revolving sprinklers are used. A wide selection of sizes is available. Those covering an area of an acre perform satisfactorily for the disposal of large volumes of waste in wooded areas but are not so desirable as the smaller sizes generally used for field and pasture irrigation. In order to minimize clogging of sprinkler nozzles a nozzle orifice of at least $\frac{1}{4}$ inch is desirable.

The quantity of waste applied will be determined by the area available for irrigation, the nature of the vegetative cover crop and the water absorbing capacity of the soil. An application of 3 to 4 inches of water at a rate of 0.4 to 0.6 inches per hour with respraying after about six days is not unusual.

The incentive for segregation of waste solids for conversion into by-products is almost entirely lacking in the fruit and vegetable canning industry because of the short canning season, the perishable nature of the wastes which require immediate conversion, and the cost of converting relatively low tonnages of high-moisture carbohydrate materials to types of by-products which normally are produced more cheaply from other sources. Con-

siderable research has been conducted in an effort to utilize cannery wastes, but little of a practical value has resulted. Pea vines from which the peas have been removed, and corn husk, cobs and trimmings are generally piled in open stacks and sold to nearby farmers as ensilage for winter cattle feeding. The solid waste material from grapefruit and orange juice preparation is usually converted into a dried cattle feed. Citrus molasses and pectin may be recovered when warranted by market conditions. Apple peels, cores and culls often are utilized in the manufacture of vinegar, pectin, jelly stock and apple syrup. Citric acid and sugar syrup are recovered from waste pineapple solids. Only minor quantities of other fruit and vegetable cannery waste solids are utilized. As to liquid cannery wastes the concentration of solids is so small as to defy profitable recovery. While the concentration of organic solids in liquid wastes originating at certain unit operations such as blanchers or cherry pitters is moderately high, the volume involved is too small to justify consideration as a source of by-product recovery.

Frozen Food Wastes

The preparation of vegetable foods for freezing are, from the planting of seeds, harvest of crops, washing, inspection and other preparatory procedures up to the final step of preservation by freezing, the same as those employed by the canning industry where preservation is accomplished by heat sterilization. The freezing of vegetables originated in canning plants and in some cases both canning and freezing are still performed in the same plant. Contaminated waste waters of the two industries therefore are of a similar nature.

Methods for the treatment and disposal of wastes from frozen vegetables were developed by the canning industry and continued or adopted without change by the newer frozen foods industry. Screening with subsequent disposal by lagooning or more recently by spray irrigation are the methods of treatment in use. For information concerning these treatments refer to the preceding section on canning wastes and to the references given at the end of this chapter relating specifically to frozen food wastes.

Dairy Wastes

The dairy industry comprises several different types of operations in which milk is handled or processed into milk products. Milk plants may be classified as receiving stations, bottling plants, creameries, cheese factories, condenseries, ice cream plants and dry-milk product plants. Often two or more of these operations are combined in a single plant. The type of waste discharged from a milk plant will reflect the particular handling or manufacturing process in use.

A survey should be made to determine the milk or milk product losses

incurred at each point throughout the entire plant where they are handled. Such surveys have shown large losses of economic importance, the correction of which has led to disposal costs. A program of pollution abatement therefore logically starts with waste prevention before considering the second step involving waste treatment and disposal.

The Waste Disposal Task Committee of the Dairy Industry Committee has listed seven sources of waste losses in their report on "Waste Prevention in the Dairy Industry."* Suggested remedial measures are given as follows:

"1. Leakage.

Caused by: pumps, sanitary fittings, plate heaters and coolers, clarifiers, separators, homogenizers, filling machines.

The remedy: (1) proper assembly of all parts; (2) proper maintenance of all parts with special attention to ground joints; (3) use of good gaskets properly installed.

"2. Overflow.

Originating at: receiving tanks, storage tanks, pasteurizers, hot wells, cheese vats.

The remedy: (1) use of positive type pumps; (2) use of liquid level controls or signal devices on vats and storage tanks; (3) installation of nonoverflow whey removal tanks at end of cheese vats.

"3. Spillage

Caused by: careless handling of products at: receiving tanks, weigh cans, vats, churns, filling machines.

The remedy: (1) improved equipment design and selection; (2) employee education and supervision in exercising more care in handling all products.

"4. Freezing-on

Caused by: Milk and milk product coolers, ice cream freezers

The remedy: (1) proper design; (2) proper adjustment of refrigerant controls; (3) shut off refrigeration before end of run.

"5. Willful Waste

Such as: separated milk, buttermilk, whey, spoiled products.

The remedy: finding suitable use for these products—for example: drying or condensing for human consumption or feeding to animals either direct or after condensing or drying.

"6. Residual Waste

Caused by: all products which adhere to surface of containers and equipment such as cans, receiving equipment storage tanks, pasteurizers, evaporators, dryers, sanitary piping.

The remedy: (1) equipping can washers with drip saver and a volumetric rinse; (2) constructing and installing all equipment and sanitary pipes for good drainage of milk and milk products; (3) complete removal of dairy products from all

* The Dairy Industry Committee, Barr Bldg., Wash. 6, D. C. Price 50 cents.

equipment and sanitary pipes before washing by prerinsing and utilizing the prerinse.

“7. Carry over

Caused by: entrainment in water from vacuum pans.

The remedy: (1) proper design; (2) use of level controls; (3) use of entrainment separators.”

TABLE 24-2. APPROXIMATE QUANTITIES OF BOD IN VARIOUS PROCESS WASTES*

Process	Lb of 5-day BOD per 10,000 lb milk or milk equivalent
Receiving and cooling milk.....	6
Tank-truck delivery to and from plant, including washing tank truck.....	1
Storage of fluid product in tanks.....	1
Evaporating whole milk, floor waste.....	2
Evaporating whole milk, entrainment loss.....	1
Canning and sterilizing evaporated milk.....	2
Spray drying whole milk.....	1
Cream separating.....	2
Cream pasteurizing, cooling and can filling.....	2
Separated milk pasteurization, cooling, and can filling.....	2
Cottage cheese or casein manufacture.....	16
American-cheese making, unwashed curd.....	10
American-cheese making, washed curd.....	16
Separated-milk condensing, plain, floor waste.....	3
Separated-milk condensing, plain, entrainment loss.....	0.5
Separated milk condensing, sweetened, including barreling floor waste.....	6
Separated-milk condensing, superheated.....	12
Separated-milk condensing, sweetened, entrainment loss.....	0.5
Separated-milk drying, spray process.....	1
Separated-milk drying, roll process.....	16
Whey condensing, sweet, floor waste.....	8
Whey condensing, sweet entrainment loss and volatile.....	2
Whey condensing, acid, floor waste.....	8
Whey condensing, acid, entrainment loss and volatile.....	4
Whey drying, spray.....	5
Buttermilk condensing, floor waste.....	8
Buttermilk condensing, entrainment loss and volatile.....	4
Milk pasteurization, cooling and bottling (glass).....	8
Milk pasteurization, cooling and bottling (paper).....	6
Ice-cream mix making, vat.....	4
Ice-cream mix making, pan.....	4
Ice-cream freezing.....	0.5
Cultured-buttermilk making.....	5
Butter churning and washing.....	2

* From “An Industrial Waste Guide to the Milk Processing Industry.”, U. S. Public Health Service.

For an elaboration of the above points consult the reference cited and also "An Industrial Waste Guide to the Milk Processing Industry"* and the numerous articles listed in the selected references. Considerable attention has been paid to waste reduction by the milk industry. Other food industries would do well to emulate their example.

The approximate loss in terms of pounds of 5-day BOD per 10,000 pounds of milk or milk equivalent (quantity of milk product derived from one pound of fluid milk) from the major processes in the milk industry is given in Table 24-2 assuming the use of modern equipment and good plant operation.

Although reduction below the above enumerated values is possible under the most efficient operating conditions these values serve as a useful guide in determining if above average losses occur for specific operations. The values listed above are subject to revision and differ from earlier published values. Only the currently approved values should be used.

The following example, using Table 24-2, shows the calculation for individual and total losses for a plant canning evaporated whole milk. The plant receives an average of 90,000 pounds of milk during the peak season based upon the receipts for the 10 top days. Of this quantity 60,000 pounds are received in cans directly from the farmer and 30,000 pounds in tank trucks. The loss calculations are as follows:

		Lb BOD
Received in cans.....	6×6	36
Received in trucks.....	3×1	3
Storage in tanks.....	8×1	8
Evaporating whole milk, floor wastes.....	8×2	16
Evaporating whole milk, entrainment loss.....	8×1	8
Canning and sterilizing.....	8×2	16
		—
Total loss per day.....		87

In this hypothetical plant a standard loss of milk solids in an amount which would yield a plant waste effluent containing 87 pounds of 5-day BOD may be expected. A waste survey of the combined plant effluent in terms of flow and 5-day BOD for use in calculating the loss in terms of pounds of BOD, will reveal whether the plant effluent conforms with the standard maximum load. A similar survey of each individual operation will reveal whether abnormal losses exist. If any is found, application of the appropriate remedial measure, as previously enumerated, is indicated.

Of major concern from the standpoint of pollution is the willful discharge of excess separated milk, unwanted milk by-products or occasional batches

* *Public Health Service Publication No. 298*, U. S. Government Printing Office Washington, D. C. (price 15¢).

of sour milk. The processing units of the dairy industry are not always geared to maximum milk production so that surpluses of separated milk, buttermilk or whey, in particular, do occur. Complete utilization of these materials presents problems of an economic nature as well as the development of new industrial uses for milk by-products. Until such time as the market is capable of absorbing all the milk produced it is essential that surpluses be returned to farms for animal feeding. Occasionally, it has been found that surplus material may be discharged to domestic sewage treatment plants, not by indiscriminate dumping into sewers, but by proper prearrangement with the sewage plant operator. Several possibilities exist according to the treatment plant facilities: controlled discharge during minimum sewage flow, increased filter recirculation, increased aeration, chemical pretreatment, direct hauling and discharge into digesters, etc. Such cooperation between industry, whether it be a milk plant or other food processing plant, and municipal sewage treatment works has repeatedly been found to be to the advantage of both parties.

Even though the maximum in waste reduction and by-product utilization is achieved, some milk waste inevitably must be disposed of. This brings us to the second consideration, namely, waste treatment and disposal.

Waste treatment and disposal may be accomplished by several methods depending upon the type, strength and volume of waste, degree of treatment required, extent of waste prevention, by-product recovery, and numerous local factors. The most important treatment and disposal methods are:

1. Discharge to municipal sewage treatment plants
2. Biological filtration
3. Activated sludge
4. Simple aeration
5. Land disposal
 - a. surface irrigation
 - b. subsurface absorption
 - c. spray irrigation

Discharge to a municipal sewage treatment plant offers the most satisfactory method of disposal. This method should be fully explored by consultation with city and state sanitary engineers. In the case of a new milk processing plant seeking location in a city, or the construction of a new domestic treatment plant or enlargement of an old municipal plant to handle waste from an existing milk plant, the expected load tributary to the milk plant may be computed from the values given in Table 24-2 as a basis for discussion. It may well be found that it is more economical for the milk plant to be assessed, wholly or in part, for additional construction

or operating charges at the city treatment plant rather than to undertake its own treatment and disposal. Or, it may be found that partial pretreatment at the milk plant prior to discharge to the city sewer may be desirable or even necessary. Equalization of milk waste discharge may be sufficient pretreatment particularly if combined with partial aeration to effect a BOD reduction. For a city sewage works to remain a satisfactory method of disposal it is essential that the operation of the dairy plant be maintained at all times at a level which will insure that the agreed upon milk losses are not exceeded.

The principles of biological filtration and its many modifications have been applied extensively to milk wastes and have found a degree of favor because of their relatively simple and economical operation. Construction costs, particularly for large units, may however exceed those involving other types of secondary treatment such as activated sludge. The so-called standard single-pass biological filter has largely been superseded by the high-rate recirculation types of filters. The latter allow greater loadings; hence lower initial construction costs, reduce or eliminate the tendency of filter plugging, and operate at higher efficiencies.

In essence biological filtration depends upon applying waste to an inert medium (rock, tile, etc.) on whose surfaces bacteria and other microorganisms adhere as gelatinous growths. As the waste trickles over these biological growths organic matter is adsorbed and digested. The filter is so constructed as to permit a free flow of air through it, thereby maintaining the aerobic environment necessary for rapid and odorless stabilization of organic matter.

For very small milk plants the fill-and-draw recirculation type of treatment plant may be considered. This system consists of a small collection sump, a hopper-bottom tank (which serves as an equalizing tank, recirculation supply, and settling tank), and a rock filter. Wastes are pumped from the raw waste collection sump to an equalizing tank capable of holding the entire flow from one day's operation. From this tank the waste is pumped to the filter at such a rate that it will be recirculated about 10 times during a 24-hour period. The equalizing tank is emptied in the morning before fresh waste is again admitted to the treatment plant. Sludge which has accumulated in the hopper is drawn off to a sludge pit before discharge of the treated waste.

Modern biological filters for milk wastes may be of either single-stage (a single filter) or two-stage (two filters operated in series). In either case recirculation is employed. The single-stage filter has been recommended where an effluent having considerable residual BOD (70–100 ppm) is acceptable. Raw wastes are admitted to an aeration tank having the functions of providing for continuous recirculation, equalization, sludge sedimentation,

and aeration. The latter is necessary to prevent the development of septic conditions. Waste from the aeration tank is applied to the filter by means of a pump whose capacity is 8 to 10 times the average rate of raw waste flow. After passing through the filter the waste enters a weir box in which the weir is so set as to discharge a volume of waste equal to the flow of raw waste and return the balance of the filter effluent to the aeration tank for further recirculation. The discharge filter effluent passes through a settling tank before finally leaving the treatment plant. Sludge from both the aeration tank and settling tank is drained off from hoppers through sludge drainage lines in the case of smaller installations. In larger installations mechanical sludge collection equipment is preferable, and may be required to avoid loss of sludge into the final effluent.

Two-stage recirculation filters are more efficient and are capable of effecting BOD reductions of 90 to 95 per cent so that final effluents well below 50 ppm should be obtained depending upon the raw waste BOD, filter loadings, and degree of recirculation. With this type of filter the effluent from the primary filter enters a weir box with the weir so adjusted that a volume equal to the raw waste flow enters a pump sump with the balance returning to the aeration tank for recirculation through the primary filter. A second recirculation pump delivers waste from the pump sump to the secondary filter whose effluent enters a second weir box. The weir is adjusted so that a volume of waste equal to the flow of raw waste discharges to a settling tank with the balance of the waste returned to the pump sump for further recirculation through the secondary filter.

The activated sludge process has been applied successfully to milk wastes to effect a very high degree of treatment. Construction costs are lower than for biological filters but operating costs are higher. More careful operating control is required. There is some difference of opinion regarding the ability of activated sludge plants to handle shock loads to the same degree as do biological filters.

Activated sludge plants operated on the principle that organic matter is readily transferred from a waste (or sewage) to the surfaces of previously formed biologically active sludge produced under aerobic conditions. The organisms inhabiting the sludge particles stabilize the adsorbed organic matter through oxidative processes converting part of the organic matter to additional sludge. The success of the process depends upon intimate contact of waste with biologically active sludge, maintenance of the proper ratio of sludge to incoming organic matter, the maintenance of an adequate supply of dissolved oxygen to insure aerobic conditions, and the disposal of excess sludge.

Several types of activated sludge processes are available. Air may be supplied either by several types of mechanical aerators, by diffusion of com-

pressed air, or by a combination of both. Contact of the waste and sludge for adsorption and oxidation of organic matter may be conducted in a single stage or in multiple stages. A roughing filter prior to activated sludge treatment may be employed to protect the activated sludge oxidation process from deterioration by shock loads. The biological activity of the sludge may be maintained in the same tank which accomplishes the adsorption and oxidation processes or renewed in separate reaeration tanks. Provision must be made for the separation of the sludge in a secondary settling tank to remove the sludge solids before final discharge of the treated waste and for the purpose of returning part of the activated sludge to the aeration tank to maintain the desired sludge concentration. The unwanted excess sludge is discharged into the primary settling tank for removal from the system together with those solids which separate from the raw waste during its passage through the primary settling tank.

The insoluble solids separated by primary and secondary sedimentation during the treatment either through biological trickling filters or activated sludge plants are putrescible and must be disposed of by some appropriate means. This may be a costly procedure. The relatively small quantities of sludge from small treatment plants may be hauled in tank trucks for disposal on land. With larger quantities of sludge more elaborate procedures are necessary. Anaerobic digestion may be utilized to convert putrescible organic material to gas and a humus-like sludge. This digestion is conducted in a closed tank. For best results the digesting sludge must be artificially heated. Properly digested sludge dewatered readily by vacuum filtration or on specially constructed sludge drying beds. Under some circumstances digested sludge may be lagooned. Even at some of the larger plants digested sludge is hauled in tank trucks for final disposal on land.

Of recent development is a system of treatment which may be designated as plain or simple aeration to distinguish it from the activated sludge process. In the simple aeration system the sludge is aerated until it attains a high degree of stabilization. Several plants have operated without any sludge removal and others with only periodic removal. A full appraisal of simple aeration has not yet been made. Reductions up to 99.4 per cent have been reported. The design and operation are relatively simple. Larger aeration tank capacity and a greater air supply are needed. The additional cost of these features may, however, not be as great as for the construction and operation of sludge digestion and disposal.

Three types of land disposal are in use: surface irrigation, subsurface absorption, and spray irrigation. The first two are restricted to small installations.

Limited quantities of waste may be applied by broad surface irrigation providing the waste is distributed uniformly, the soil has a good water ab-

sorption rate, and is cultivated frequently. Distribution of the waste may also be accomplished by means of furrows. If odors become a problem they may be controlled by prechlorination. Disposal by surface irrigation may be curtailed or entirely prevented by subfreezing temperatures.

Subsurface irrigation is an adaptation of the well-known residential septic tank discharging to a subsurface tile drainage system. In order not to overload either the septic tank or the drainage system every effort must be maintained to reduce to the minimum both the volume of waste and its strength. At small cheese factories, for example, provision must be made for separate collection and disposal of whey to condenseries or to farmers for animal feeding.

Disposal of milk wastes by spray irrigation is a new development which may prove to be of wide application to the dairy industry. The equipment, operation and limitations of this method are essentially those employed for the disposal of cannery wastes (q.v.). The possibilities inherent in spray irrigation are well illustrated by the following example quoted from an article* dealing with the disposal of cannery and dairy wastes by spray irrigation.

"The second plant to be described using spray irrigation is a dairy located in Southern New Jersey. In this area the winters are mild enough so that wastes may be sprayed nearly every day. On occasions when spraying is not possible, wastes are retained in the surge pit.

"This dairy receives 80,000 to 90,000 lb. of milk per day, which is processed into pasteurized milk, chocolate milk, cottage cheese, and ice cream. Approximately 75,000 g.p.d. of waste water is produced. Domestic wastes from 135 employees and wastes from a dairy barn for 130 cows are included. Condenser cooling water is bypassed. The disposal system at this dairy includes the following:

"1. Septic tanks. Wastes from existing septic tanks for domestic sewage, factory wastes, and dairy barn wastes are combined and flow to a newly constructed septic tank that provides approximately 45-min. detention for a design flow of 250 to 300 g.p.m.

"2. Surge sump. Wastes from the final septic tank discharge into an earthen basin holding 5 to 6 days flow.

"3. Pump. The pumping unit consists of a 15-hp. centrifugal pump with a capacity of 200 g.p.m. at 80-p.s.i. pressure.

"4. Irrigation main line. A total of 2,760 ft. of 5-in. aluminum pipe delivers wastes to the irrigation fields.

"5. Sprinkler lateral lines. A total of 2,240 ft. of 4-in. aluminum pipe is available for lateral lines.

"6. Sprinklers. Fifty-nine $\frac{3}{4}$ -in. sprinklers each deliver 10.5 g.p.m. at 45-p.s.i. nozzle pressure. Sprinklers are located at 40-ft. intervals on the laterals.

"7. Irrigation fields. An entire farm is available for irrigation, but only a maximum of 45 acres of hay fields are spray irrigated. The soil is a light sandy loam.

"Items 3 to 6, inclusive, together with the auxiliary tees, elbows, end plugs, valves, etc., cost \$5,817 in 1951. The total cost including items 1 and 2 and installation was

* *Sewage and Ind. Wastes*, **25**, 1034 (1953).

approximately \$15,000. The system was designed to handle 144,000 g.p.d. at the rate of 200 g.p.m. for a 12-hr. day.

Analyses of the wastes show the following range:

pH.....	7.12 to 7.6
BOD.....	250 to 355 p.p.m.
Total solids.....	516 to 650 p.p.m.
Vol. solids.....	270 to 470 p.p.m.
Ash.....	158 to 246 p.p.m.

"The system at this dairy provides for great flexibility of operation by virtue of the 5 to 6-day surge sump, the availability of excess laterals, and more hay and pasture fields than can be irrigated from the existing supply of waste water. Pump capacity limits operation to a maximum of 18 sprinklers at any one time. Normally, wastes are sprayed every other day. Laterals are changed or sprinklers turned on or off so that no more waste is applied than will be beneficial to the hay crop.

"Dairy cows are pastured in fields irrigated with waste. The New Jersey State Board of Health has given approval to this procedure providing an interval of 10 days elapses between the time spraying is discontinued and milk cows are turned into pasture."

All of the above treatment and disposal systems, except possibly for the smallest operations, require screening through a course ($\frac{1}{2}$ inch) wire mesh or bar screen to remove large inert materials which otherwise would injure or clog pumps, the waste distribution nozzles on trickling filters, spray irrigation sprinklers, etc. In larger installations grit removal may be combined with screening by reducing the velocity of raw waste flow to one foot per second through a grit removal channel.

Meat Wastes

Wastes from the meat industry may be divided into two major classifications: slaughter house wastes and packing house wastes. A third classification—stockyard wastes—may or may not be a major source of waste in conjunction with slaughterhouse and packing house operations, depending upon the extensiveness of stockyard operations. All three types of waste are highly putrescent and malodorous. When discharged untreated to a water course they lead to a rapid depletion of dissolved oxygen, damage to aquatic life, and production of odors, sludge deposits and unsightly floating scum. Chemically, these wastes are similar to domestic sewage, slaughterhouse and packing house wastes being considerably stronger.

Stockyard wastes consist of animal manure and urine, straw, unconsumed hay and other feed, dirt, rainwater, and when used, water for cleaning and flushing purposes. To the extent possible manure and fibrous materials should be removed in a dry state. Liquid wastes should be screened before admittance to sewers.

Slaughterhouses generally are small in size with operations confined to the killing of animals and dressing of meat for limited distribution. Packing houses, besides killing and dressing on a more extensive scale, process

meat by cooking, curing, canning and by other means, and generally either recover waste materials for direct conversion into a wide variety of by-products or for shipment to recovery plants. Packing houses are usually found in the larger cities and have access to municipal sewage treatment plants.

It follows that the volume and organic content of meat wastes will vary widely according to the type of operation and degree of by-product recovery practiced. Average values for slaughterhouse wastes from the killing of mixed animals has been given as 2,240 ppm BOD, 929 ppm suspended solids, 324 ppm total nitrogen, and 359 gallons per animal. Weighted average values from a number of packing houses have been reported as 909 ppm BOD, 645 ppm suspended solids, and 113 ppm nitrogen. Blood has a BOD in excess of 100,000 ppm—a very high value. Its recovery for separate disposal or by-product utilization should be practiced in the interests of BOD reduction, profit, or both, even by the smallest slaughterhouse.

The type and degree of treatment required will depend upon the volume and strength of the raw waste, how the wastes are to be disposed of, i.e., to a large or small stream or to a municipal sewage plant, and requirements of regulatory agencies. Treatment begins at the stockyard with the separation of manure and screenable solids and continues in the plant with separate collection of blood and paunch manure, the latter being handled preferably in the dry state. However, paunch manure is frequently added to the flow of liquid waste for removal by screening. While this practice may be more economical, considerable BOD and suspended solids are imparted to the liquid waste. The practice should be avoided when the liquid waste needs extensive treatment to produce a final effluent with a minimum BOD.

Grease (animal fat) removal is a most important preliminary treatment. The presence of grease leads to objectionable scum formation in streams and impairment in the operation of primary and secondary treatment units, adheres to the walls of sewers to the point where the flow of waste or sewage is reduced or occasionally completely stopped, and adversely affects the quality of sludge when used as fertilizer. As a further incentive grease removal when properly conducted yields a profit from its sale.

For the best results in recovery and quality of grease the grease recovery units should be placed as near as possible to the source of grease production. There are a number of types of grease recovering units, from screens and simple grease traps to patented devices and procedures employing aeration and chemical coagulants, including chlorine.

Septic tank treatment following screening and grease removal with the overflow discharging to subsurface absorption fields, pits, lagoons, or filter beds is satisfactory in many localities for the smaller slaughterhouses. As

the volume of waste increases recourse must be had to more involved methods of treatment. Sedimentation may be expected to remove 30 to 35 per cent of the BOD and 40 to 60 per cent suspended solids. Chemical coagulation had been used at some plants with BOD removals up to 85 per cent.

The general principles of biological filtration have been discussed in previous sections and will not be repeated. Meat wastes respond well on low-rate and high-rate trickling filters and by the activated sludge process. Wastes from large meat packing operations invariably are treated by these biological methods at the packing plant itself or in conjunction with domestic sewage at municipal treatment works. Over-all BOD reductions including primary and secondary settling may range as high as 98 per cent with activated sludge treatment and nearly as high with two-stage trickling filters when the treatment facilities are not overloaded.

Before discharge to municipal treatment plants wastes from large meat plants generally require pretreatment by sedimentation either with or without chemical or mechanical flocculation, biological filtration in roughing filters, low- or high-rate single- or two-stage biological filters, or activated sludge treatment.

A great deal of research has been devoted to the treatment of meat waste, not all of which has had enough practical application to warrant proper evaluation. In addition to the selected references given below attention is called to an excellent "Summary of Treatment Methods for Slaughterhouse and Packinghouse Wastes" by D. G. Gold, University of Tennessee Engineering Experiment Station Bulletin No. 17 (1953).

Poultry Wastes

Poultry wastes are produced when chickens, turkeys, and other fowl are killed, bled, defeathered, chilled, and frozen, with or without prior eviscerating. If not eviscerated the operation is known as "New York pack"; if eviscerated, as "full pack." In addition to these operating wastes an important source of waste analogous to stockyard waste of the meat industry originates from the cages in which the birds are held and fed. The wire holding cages are known as batteries and the wastes as battery waste. Published literature dealing with poultry wastes is confined almost entirely to that emanating from the packing of chicken.

The waste first produced, battery waste, contributes by far the greatest pollutional load. The waste consists principally of manure together with unconsumed feed, water used to wash the batteries, and water applied continuously to the floors of the feeding area beneath the tiers of batteries to keep the floors clean and at the same time raise the humidity in the battery house. Metal pans are placed under the top three tiers but seldom under the bottom tiers. The quantity of battery waste varies according to the method

of cleaning batteries, the quantity of floor water and the length of time the chickens are held. Although only meager data are available, reported data from four plants show a battery waste discharge of 333 to 833 gallons per 1,000 pounds of live chicken weight processed. This waste contained 3.3 to 26 pounds of BOD and 10.7 to 50 pounds of suspended solids. In parts per million the BOD ranged from 1,185 to 7,575 and suspended solids 3,820 to 14,480. The highest values occurred at a plant where the pans were not scraped free of manure and adhering feed, so that all of this material was included in the waste water.

It is possible to eliminate most of the manure and spilled feed from plant sewers. This will accomplish more by way of pollution abatement than any other single procedure. Catch pans should be installed so that no manure or feed reaches the floors. Pans and batteries should be scraped, without the use of water, either by hand or mechanically. The material so removed should be placed in metal drums and disposed of as fertilizer either directly to fields or to fertilizer manufacturers. The volume of wash water for final pan and battery cleaning can be reduced by improved and careful washings, for example, by high pressure spray washing with self-closing nozzles. Water used for humidifying can be completely eliminated by the use of humidifiers. With a marked reduction in battery and feeding station waste flow, segregation of these wastes with discharge to a digester would appear practical. One investigator concluded that complete elimination of manure at a particular packing plant would effect a reduction from 84 pounds of BOD to only 6 pounds per 1,000 chickens killed, and on the same basis, the suspended solids would be reduced from 158 pounds to 7 pounds, a very high degree of reduction indeed and one which could be accomplished more economically by dry handling than after the solid waste materials were flushed down plant sewers. It was recognized that complete manure elimination was not practical but that a 90 per cent reduction would be feasible. It is the consensus that any program involving pollution abatement must begin along the lines indicated above.

The first waste produced in the sequence of packing operations is that produced at the time the chickens are killed. Heads may or may not be removed according to the method of killing. Regardless of the killing procedure, blood is obtained. The BOD of chicken blood has been reported as 92,000 ppm with 56 pounds from 1,000 pounds of chicken killed. Blood constitutes the second largest source of pollution from poultry plants. The method of killing determines the extent to which blood can be separately recovered. Blood is spattered about when beheading or wringing procedures are used. Killing by dislocation is not satisfactory. Sticking of birds hung by shackles on their feet with blood collection in a cup hung to the bird's neck or by drippage into a blood collecting trough appears to offer the most

satisfactory procedure for keeping the maximum amount of blood out of the plant sewers. Blood drainage time should be adequate. Collected blood should be disposed of separately, preferably to by-product or rendering plants. If heads are removed these should be disposed of with the viscera.

The next processing waste is derived from defeathering operations which yield feathers, scalding water containing dirt, manure, and blood adhering to feathers, wax chilling water, and wax or rosin particles. The birds pass through a hot water scald and then to mechanical feather pickers and on to hand pickers. After drying the birds are dipped in molten wax, then sprayed with cold water to set the wax which is stripped off by hand to remove pin feathers. Feathers should be collected and disposed of separately. None should be allowed to enter the floor drains which should be protected by screens which serve also to retain pieces of wax finding their way to the floor. Stripped wax is refined for reuse. Wax chilling water contains so little pollutorial matter that, if desired, it may be disposed of without further treatment after screening. Scald water overflow and scald vat dump containing blood, manure and dirt constitutes a strong waste. The combined wastes from killing and picking operations at three plants are reported as varying from 321 to 1,730 ppm BOD and 257 to 1,697 ppm suspended solids. The flow per 1,000 pounds live weight is reported as 110 to 1,667 gallons with 1.1 to 4.4 pounds of BOD and 1.6 to 3.8 pounds of suspended solids.

After removal of feathers the birds are singed, cooled, and passed on to the packing room for "New York pack" or for eviscerating in the case of "full pack." No separate data are available for the character of the waste from eviscerating and washing. Viscera and the contents of the gizzards should be collected for disposal to rendering plants. These wastes should not be discharged to floor drains.

Cooling may be accomplished by air chilling in which case no waste is produced. Cooling is also accomplished by packing the birds in iced water. After cooling the birds are packed in containers, frozen and held under refrigeration. Cooling water, together with floor washings, constitute the packing room waste. Packing room wastes from three plants are reported to vary in flow from 333 to 477 gallons per 1,000 pounds live weight, with from 0.4 to 1.9 pounds of BOD and 0.2 to 1.0 pounds of suspended solids also on the same basis. A BOD of 132 and 309 ppm and 83 and 272 ppm suspended solids were reported from two of the plants.

The combined wastes from nine chicken packing plants is reported on the basis of 1,000 pounds live weight as ranging in flow from 435 to 2,390 gallons containing from 2.8 to 50 pounds of BOD and 3.4 to 52.7 pounds of suspended solids. In parts per million the BOD from five plants ranged from 290 to 1,475 and the suspended solids from 260 to 1,520 ppm.

Little factual information is available on the operation of poultry waste treatment plants. It is obvious from the foregoing discussion that as nearly complete removal as possible should be practiced with respect to manure, blood, viscera, feathers, and wax, the latter two not for BOD reduction but because of the interference of these materials in sewers and treatment facilities. Dry cleaning of floors and equipment should precede washing with water.

At very small plants septic tank treatment with subsurface absorption should be adequate.

Lagooning has been reported as satisfactory at a small plant processing 5,000 chickens per day. Blood and inedible offal are collected for disposal to a rendering plant. Feathers are collected for field disposal. The liquid wastes from scalding, decropping, defeathering, eviscerating and equipment and floor washings are passed through a $\frac{1}{4}$ -inch stationary screen to a septic tank having an average detention time of 12.4 hours per day. The overflow enters a 12-foot deep lagoon over a gravel stratum. The lagoon capacity is 300,000 gallons. The raw combined waste has a BOD of 385 ppm. The effluent from the septic tank has a BOD of 143 ppm. The BOD of the lagooned waste is 27 ppm. Ammonium nitrate is broadcast over the surface of the lagoon at the rate of 200 pounds per 10 days during the summer to a low of 100 pounds per three weeks during the winter months to hold odors to a minimum.

At large plants biological filtration with recirculation, preceded and followed by sedimentation with sludge digestion, probably is the only satisfactory method of complete treatment. Grease removal may also be required before primary sedimentation.

Poultry wastes can be handled in combination with domestic sewage at municipal treatment works providing the flow or strength does not overload the treatment works beyond design capacity. Pretreatment at the poultry plant at least to the extent of sedimentation and flow equalization may be required.

Beet Sugar Wastes

The dissolved organic matter in beet sugar wastes when discharged untreated or improperly treated into streams produces the usual oxygen depletion effects, harmful to aquatic life and accompanied by objectionable odor production. Damaging deposits of sludge consisting of soil, beet fiber and lime are likely to occur. The latter may raise the hardness of the stream water to an objectionable level for subsequent use. The stream may be adversely effected by the discharge of warm barometric condenser water.

The production of beet sugar is a seasonal operation lasting from 60 to 100 days. The seasonal nature of beet sugar production and the very large

TABLE 24-3. REPRESENTATIVE VALUES OF UNIT PROCESS WASTES FROM BEET SUGAR MANUFACTURE*

Source of waste	Flow/ton beets (gal)	BOD (ppm)	Suspended solids (ppm)	BOD /ton sliced beets (lb)
Flume water.....	2,600	210	800-4,300	4.5
Pulp screen water.....				
Bottom dump cell.....	240	980	530	2.0
Side dump cell.....	1,420	500	620	5.9
Continuous†.....	400	910	1,020	3.0
Pulp press water.....	180	1,710	420	2.6
Pulp silo drainage.....	210	7,000	270	12.3
Lime cake slurry.....	90	8,600	120,000	6.5
Lime cake lagoon effluent.....	75	1,420	450	0.89
Barometric condenser waste.....	2,000	40		0.67
Steffen waste.....	2,640‡	10,500	100-700	231(3)

* Adapted from Tables 2 and 3 in "Beet Sugar—An Industrial Waste Guide to the Beet Sugar Industry," Federal Security Agency, U. S. Public Health Service (1950).

† Pulp transported by water.

‡ Per ton molasses processed on a 50% sucrose basis.

volumes of waste waters involved impose definite limitations of practicability in the treatment and disposal of beet sugar wastes. To a large extent improvement in the quality of the waste discharged from beet sugar plants depends upon the elimination or reduction in volume or strength of wastes from unit operations. For many plants this calls for a program of modernization, possibly factory-wide, which by increasing sugar recovery and conserving on water usage reduces the cost of treatment for residual wastes. A logical approach to a discussion of beet sugar wastes, therefore, is to consider the source, treatment and possibilities of reuse or elimination of each type of waste originating in the factory rather than just the final combined factory waste effluent. Representative flow, BOD and suspended solids data for unit process wastes are given in Table 24-3.

The first waste water produced is that used to simultaneously flume and wash beets from the storage area to the factory, together with the water from the beet washer located at the end of the flume. This waste has the largest flow of any unit operation, with an average flow of 2,600 gallons per ton of beets. It contains large quantities of soil, pieces of beets, beet roots and leaves, together with some dissolved sugar and other organic materials. The BOD generally varies between 150 and 250 ppm, averaging 210 ppm, but when beets become frozen or decomposed the BOD is much higher.

The large volume of flume water suggests reuse and this is being done at a number of plants. Pieces of beets and beet roots are removed by screening. Soil and the more readily settleable suspended organic matter are

removed by plain sedimentation in settling tanks equipped for mechanical removal of sludge. Coagulation with lime may be used as an aid in settling. Sedimentation of flume water is also performed in lagoons, but inability to remove deposited solids makes this procedure less satisfactory. Periodic chlorination of recirculated flume water may be necessary to control odors. Recirculation markedly reduces the total volume of waste requiring treatment.

When flume water is not reused, treatment may consist of screening, grit removal, and sedimentation, the latter with or without chemical coagulation. Sludge is removed continuously and dewatered either by vacuum filtration or impounding in sludge ponds. Unless large stream dilution is available, settled waste requires lagooning.

The second source of waste is pulp screen water which, according to the type of diffuser cell (bottom dump, side dump, or continuous), varies considerably in volume (average values: 240 to 1400 gallons per ton of beets, depending on cell type), BOD (average: 500 to 1,000 ppm), and suspended solids (average: 530 to 1,000 ppm). The more modern use of conveyor belts to handle spent pulp is to be preferred since, as always is the case with fluming organic materials, soluble organic constituents leach out into the flume water, suspended solids are added, and the volume of waste water which eventually must be treated is increased. Pulp screen water is derived in part from the spent pulp when drained on screens, together with water used to flush out bottom and side dump extraction cells and water used for fluming pulp to drainage screens. The use of modern continuous diffusers with mechanical conveyance of spent pulp eliminates pulp screen water.

Pulp screen water may contain from 300 to 600 ppm of sucrose and some pulp both of which should be recovered rather than discharged to create treatment and pollutional problems. Reuse of pulp screen water for diffusion battery water has long been practiced in Europe, but only to a small extent in this country. In addition to sugar and pulp recovery, use of this water conserves heat (temperature of waste about 50°C) and reduces the quantity of fresh water required. Prior to reuse as diffusion battery water, fine screening or sedimentation is usually employed to remove suspended solids which might otherwise obstruct the flow in the diffusers. Sedimentation may be assisted by lime, acid, or chlorination. Also, prior to reuse, control of thermophilic bacteria by heat or by chlorination is necessary. Pulp screen water sometimes is reused in the making of lime cake slurry or to dilute molasses in the Steffens process. There has been a reluctance on the part of some operators to reuse pulp press water based upon the aforementioned presence of suspended solids and thermophilic bacteria and also because it is thought that a build-up of nonsugar solids might retard

sugar crystallization. A sufficient answer to these fears is the extensive foreign practice, particularly in Sweden, involving reuse of pulp press water beside some successful reuse in this country.

Spent beet pulp makes high grade stock feed. After screening the pulp is handled in either of two ways. Where a dry feed is produced the screened pulp is further dewatered in presses. The press liquor is a waste similar to pulp screen water, but is lower in volume (average: 180 gallons per ton of beets), lower in suspended solids (average: 420 ppm), but greater in BOD (average: 1,710 ppm). It is higher in recoverable sucrose. The advantages for reuse and the procedures for reconditioning press water for reuse are the same as just given for pulp press waste.

Until such time as reuse is fully adopted for pulp screen water and pulp press water, these wastes must receive treatment. Screening through vibrating screens having 30×40 mesh wire cloth recovers pulp in economic quantities. Lime coagulation of the screened waste with sedimentation, continuous sludge removal, and dewatering by vacuum filtration or discharge to sludge ponds helps to reduce the pollutional quality, but still leaves a waste which requires lagooning.

Instead of drying the pulp, it may be stored until fed in open silos. The liquid which drains from the pulp is not suitable for reuse. The pulp undergoes a degree of fermentation or decomposition. It has a pH of about 4 and a BOD averaging about 7,000 ppm. The flow of waste continues after the sugar campaign is over and may become even stronger, although less in volume than the portion retained until warm weather. From the standpoint of pollution control or reduction in treatment costs, the only answer lies in abandonment of silo storage in favor of conversion to dry feed and reuse of pulp press water.

Returning to sources of waste from unit operations in the sugar production departments, the next waste is lime cake. This waste arises from the addition of lime to raw battery juice, followed by carbonation and filtration. The process is repeated. The juice is then treated with sulfur dioxide and filtered a third time. In an alternative purification procedure known as Steffens house operation, calcium saccharate derived from a lime treatment of Steffens house molasses is added to the raw juice instead of lime. In either case, lime cake is obtained which contains nonsugar organic solids and finely divided beet pulp. The moisture content is about 50 per cent so that the cake may be handled mechanically. The cake may be burned to produce calcium oxide for reuse.

Unfortunately, however, it is generally customary to add water to the lime cake to produce a slurry which can be pumped for disposal. On the average, some 90 gallons of lime cake slurry are produced per ton of beets processed. The slurry has a BOD of 7,000 to 10,000 ppm. The pH is about

11.7. Lime cake slurry must be impounded and retained for the entire campaign and thereafter until such time as high river flow permits controlled release of the supernatant liquor. The supernatant still has a high BOD, about 1,400 ppm, with about 450 ppm suspended solids. Obviously, to maintain pond capacity, settled lime must be removed after the liquid has been drawn off.

The juice, now partially purified by the carbonation process, is concentrated in multiple-effect evaporators and filtered. The filtered sirup is further concentrated in vacuum pans to the point of crystallization and sugar recovered by centrifuging. Further evaporation yields second and third crystallizations which, being impure, are remelted and returned for recovery in the first crystallization. The molasses from the third crystallization is sold for various industrial purposes or utilized in Steffens house operation for further recovery of sugar. From the above evaporations two wastes are produced. One is filter cake which is added to the lime cake previously discussed. The second waste comprises barometric condenser water and evaporator condensates. The BOD is low and the water carries some Btu. It is reused extensively. It may be used for fluming and washing beets, for diffusion battery water, for cleaning filters, or for boiler feed water. Where spent pulp is flumed or lime cake is made into a slurry, it may be used for these purposes. There is no occasion to waste any of the approximate 2,000 gallons which are produced per ton of beets processed.

In Steffens plants a diluted molasses known as "Steffens waste" is produced. This is the filtrate remaining after separation of a calcium sacchrate precipitate. Steffens waste is the strongest waste produced in beet sugar manufacture, having an average BOD of 10,500 ppm. Some 2,640 gallons are produced for each ton of 50 per cent sucrose molasses produced.

The solution to the problem of Steffens waste lies in profitable by-product conversion. Experimental work suggest the feasibility of incorporating the waste in beet pulp feed. A similar practice has been followed in the citrus industry where citrus molasses is used to fortify dried citrus pulp feed when other outlets for the molasses are not profitable. Some Steffens waste is utilized for monosodium glutamate production or for further sugar recovery by the barium process, but again liquid end wastes are produced which must be disposed of. Fortification of pulp stock feed may be resorted to for utilization of concentrated liquid end wastes.

Steffens waste not utilized in by-product recovery generally is lagooned. Because of its high BOD, detention periods must be long. Even after moderately long lagooning the considerable residual BOD necessitates careful control of the rate of discharge to streams.

In addition to the unit process wastes discussed, waste waters result from the cleaning of equipment, floors, and the washing of filter cloths.

These wastes enter factory floor drains and generally are included along with wastes requiring treatment.

Complete modernization involving: (1) elimination of practices leading to avoidable waste production (elimination of pulp screen by use of continuous diffusers with mechanical conveying of pulp and elimination of pulp silo drainage through pulp drying); (2) reuse (flume water, pulp press water, condenser water and lime cake calcining); and (3) by-product recovery (Steffens waste) still leaves for treatment the miscellaneous wastes cited above and such overflow from recirculation systems as it may be necessary to discharge to prevent detrimental accumulations of nonsugar solids in recirculation systems. Modernization to this degree would achieve substantial reductions in the volume and strength of waste requiring treatment, although it must be recognized that reuse, while reducing volume, does not reduce correspondingly the pounds of BOD requiring treatment.

Lagooning probably will continue as a basic method of treatment. With a lowering of the volume of waste requiring treatment, lagoon detention times can be increased to provide for increased waste stabilization. Better control of lagoon odors would increase acceptance of lagooning.

Biological treatment has not met with much acceptance, partly because of the time required to develop effective biological growths. A combination of lagooning and biological filtration may offer advantages.

Miscellaneous Food Wastes

There are a number of other food product wastes, many of which are represented in the literature by only one or two references. The methods for treating and disposing of these wastes follow in general, with appropriate modification for unusual waste characteristics, methods which have already been discussed. The references to some additional food plant wastes cover the more recent literature.

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25. CHEMICALS IN FOODS

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The subject of chemicals in foods has been of wide interest, especially in recent years as a result of technological developments in which chemicals are employed and because of the investigation of chemicals used in the food industry by a committee of Congress. A large industry, the food industry, is undergoing revolutionary changes induced by the impact of science and the evolution of our social organization. Some of the recent technical applications are being challenged.

There has been considerable misunderstanding regarding the use of chemicals. Their purpose has not always been well understood by those who have written about the subject, the public has not been properly informed, and even some members of Congress who were on the investigating committee did not fully understand the technological needs involved in the use of some chemicals. The fact that chemicals are used to promote the nutritional value of foods or functionally to promote quality, stability, and consumer acceptance is not generally appreciated. The use of chemicals in foods is often wrongly associated with adulteration by substitution or addition of preservatives and use of surrogates of various kinds. In modern food technology chemicals are used chiefly for their functional value or nutritive value. A brief discussion may clarify the various points of view.

F. L. Hart¹ has made interesting contributions to the subject of food adulteration. Historically, we know that adulteration of foods has been practiced ever since history began. It has been pointed out that the more expensive and the more complicated our processing of foods becomes, the greater will be the need for functional additives. Because of the increased number of items produced, and the increased number of items in each product, manufacturing becomes difficult, especially if some of the in-

redients are in short supply. Because at certain times, such as war emergencies, foods necessarily disappear from certain markets, imitations and adulterations to replace these disappearing foods are practiced.

In war time, unfortunately, the government becomes a contributor to adulteration by permitting imitations or substitutes for food. This was especially true during World War I and World War II. In World War I substitutes for wheat flour became legal, additions of cereals to meat products were permissible, and substitutes for milk, eggs, and coffee were developed with government approval. Following the War, the advent of the natural products and the lowering of prices of these natural products tended to drive the imitation and the adulterated product from the market.

It is from the background produced by practices of this kind that the consumer usually approaches the problem of chemicals in food. However, there is a vast difference between the approach of the food technologist and food chemist, and that of the manufacturer who is degrading food. The modern manufacturer and his technical staff seek to improve foods which may have been highly refined during manufacturing. They may add chemicals to improve the nutritional value of foods or to promote better acceptability by enhancing appearance, flavor, taste, stability, and physical characteristics. This approach is consistent with the trends of the modern food industry, which prepares food ready for the table and which must meet the consumer demands for quality, good flavor, and good physical appearance. To meet this demand, the technologist utilizes chemical and physical knowledge to make these foods as nutritious, flavorful, and physically acceptable as possible. This is vastly different from the practice which prevailed in Roman times and in more recent periods in western Europe where manufacturing of food, such as the grinding of wheat, was prohibited because in the form of flour, the product could be more readily adulterated by the manufacturer. It is also vastly different from the concept of those who have not realized the great changes science has made in the food industry, and who consider that scientific knowledge is being used to adulterate or cheapen foods.

History of Food Legislation and Some Early Attempts to Use Chemicals in Food

It is not the purpose of this chapter to discuss food adulteration except to differentiate the use of chemicals by the food technologist for functional or nutritive value from the use of chemicals as adulterants as defined above. It is believed timely to discuss the subject of chemicals in foods in a broad way, and to point out some of the difficulties which arose as society became more specialized, and the manufacturing of food moved from the home to the factory. Adulteration and imitation of foods became a matter of concern

to the government centuries ago, and when chemical science became sufficiently advanced, it was possible, as Accum² had shown over one hundred years ago, to detect some of the adulterations quite readily. As science developed, it became possible for adulterators to practice deception. Some of these practices were clever and taxed the ingenuity of the government scientist to discover them. We see how the additions of water and preservatives of various kinds to milk were gradually eliminated. Purity and quality of flour became well established. The background of legal protection for the consumer dates back in English history to the Magna Charta, 1215. Early in U. S. history legislation to protect the consumer engaged the attention of state and national governments and Congress passed a number of acts. The first act concerned the importation of adulterated drugs in 1848, and in 1890 Congress passed an act to prevent the importation of adulterated food. In 1906 the first important national food law, the Wiley Bill, was passed³.

Congress also passed the Federal Meat Inspectors Act in 1906. In 1938 the Federal Food, Drug and Cosmetic Act replaced the Federal Act of 1906 which had been amended several times. This act was supplemented by the Federal Trade Commission Act of 1938 which prohibited false and misleading advertising, and is supported by similar state and municipal legislation.

The Federal Food and Drug Act of 1906 prohibited the harmful adulteration and misbranding of foods. It was administered by the U. S. Department of Agriculture. The 1938 Food, Drug and Cosmetic Act prohibits injurious or deceitful adulteration, and misbranding of all foods and drugs. It is administered today by the Food and Drug Administration of the Department of Health, Education, and Welfare. State and municipal laws based on the federal law have been generally adopted.

Let us examine briefly the early background on the use of a number of chemical additives whose functional properties play a large part in the processing of foods. Shortly after alum baking powder was introduced as a leavening agent, a controversy arose concerning its safety. H. Wiley, in 1889, issued Bulletin 13 Part 5 on baking powders, including alum. The fact that this powder was low in cost and had excellent qualities as a leavening agent made its competitors seek to remove it from the market by insinuating that the powder was too toxic for use in such large amounts as were required for leavening purposes. Wiley⁴ recommended a law to cover the composition of powders and the per cent of leavening gas released. He was concerned about the possibility of the safety of alum powders. The manufacturers of alum powder should find the law advantageous "provided they could succeed in proving that such powders produced little or no injury to the health of the consumer." This controversy took

many years to settle, and finally the nontoxic nature of alum was definitely accepted. One is inclined to believe that this controversy colored the thinking of several generations on the question of chemicals in foods.

Another situation of interest arose in connection with the use of dough conditioners. About 1915 Kohman and co-workers at the Mellon Institute discovered that CaSO_4 and KBrO_3 were useful as dough conditioners. The young, recently mechanized baking industry had been faced with many problems, such as hard water, SO_2 in water, seasonal and regional variations in flour, low protein, bucky doughs, et cetera. The use of CaSO_4 and KBrO_3 improved the operating conditions in the bakery. However, their use was opposed by certain government agencies as well as by some nutritionists. It was stated by opponents that plaster of Paris was being added to doughs. The functional value of the additive was not properly recognized and understood by the layman. The food faddist saw an opportunity to attack white bread because of its nutritional deficiencies and because a definite idea by the nutritionist for improvement was lacking. Today the use of calcium salts is approved by the Food and Drug Administration, and liberal amounts of calcium are permitted in standardized bread.

Somewhat similar complaints were leveled against oxidants in flour. In many instances such oxidants as KBrO_3 , ClO_2 , and formerly NCl_3 , are used to age flours when it is impossible to age them by long storage. Senator Ladd opposed the use of NO_2 and chlorine. While it was found by Mellanby⁵ in 1947 that NCl_3 treated flour is a hazard for dogs, no data had ever shown that there is any danger to humans. The Food and Drug Administration has permitted the use of KBrO_3 and ClO_2 as suitable for the treatment of flours. After a well organized and effective hearing the Food and Drug Administration Nov. 27, 1948 removed nitrogen trichloride from the list of permitted additives. However, it was clear that no evidence was offered indicating that nitrogen trichloride was toxic at the levels used in bread. In fact, human subjects fed for months at high levels showed no evidence of injury as determined by electroencephalogram tests, nitrogen output, or other diagnostic signs indicative of injury.

The treatment of flour by oxidants has an important economic aspect, and the modern baking industry with its mechanized equipment for bread making would find it difficult to operate and to produce uniform and high quality products without oxidants to age and modify flours. Cake flours, so successfully used in the home, are chlorine treated to condition flours for quality cake production.

About 1912 studies made in Ohio by Marine and Kimball⁷ showed that the addition of iodine to salt or drinking water controlled endemic goiter. Endemic goiter is prevalent in the central states, and consequently measures were taken to promote the use of iodized salt. The Food and Drug

Administration and the Food and Nutrition Board of the National Research Council have approved the use of iodized salt.

When we consider the possible sources of contamination in foods, it is well to bear in mind as Parsons⁸ reminds us that some elements are present in significant amounts naturally. Copper may be present in ox liver and calf liver in amounts of 20–80 ppm in the former and 150 in the latter. Lead may be present in amounts of 80–100 ppm in oysters. Wholemeal flour may contain 2–50 ppm zinc; fluorine may be found in tea at levels of 100 ppm. Residues from harvesting, such as spray materials, tin and other metals from which the can is made may add substantially to the amounts naturally present in a food. He also suggests a table of legal tolerances.

Amos⁶, an English chemist, has set up criteria for the addition of chemicals to foods which, he believes, will protect the consumer: (a) The use of the chemical reacts to the benefit of the community by materially improving the standard of quality of the food by retarding the onset of deterioration, reducing wastage, or by significantly enhancing the dietary value of the food; (b) The chemical compound employed and the reaction products to which it gives rise do not significantly diminish the nutritive value of the food, and do not have any ill effects when consumed in the quantities provided by a normal intake of this food.

Technology and Food Production

It is highly important that to avoid the creation of false and prejudiced ideas an educational effort be made to place certain technological views before the consumer. This educational effort has been carried on by means of symposia at meetings of the Institute of Food Technologists, the American Chemical Society, and the American Association for the Advancement of Science.

The technologist is faced with a multiplicity of problems in respect to raw materials, processing, packaging, consumer tests, and stability of foods. In addition he must see that his products meet government standards at every level, and are not too critically poised to come under the criticism of physicians and health officers. He must educate the consumer in those aspects of technical importance involved in the use and acceptance of his products. This brings into play the function of management, especially its coordinating activity. The laboratory must be responsive to consumer needs and demands. It becomes necessary to educate the sales and advertising departments, and in turn these departments should keep the laboratory informed concerning the new developments of competition and the buying habits of the public.

Our food supply is not so plentiful that we can be complacent about it. Some of our best agricultural farm land is being taken over by cities.

Since 1882 Ohio lost 1,620,000 acres of farm land to encroachment by cities and to other causes. A sound study of land use is indicated to enable us to provide for our food needs. Blaxter⁹, an English scientist, gives figures that are significant: 1 acre of wheat produces calories for 2.4 people per year, lysine 1.8, calcium 0.3, and no vitamins A, C, and D. One acre produces milk sufficient to feed in calories 0.6 individuals, lysine 4.1, calcium 3.6, and vitamin A 2.0. This shows the compromise that must be made to feed our growing population, and the need for extending the protein, mineral, and vitamin resources by every possible means, thereby permitting food production to be geared to the growth in population. It is estimated that in 1975 our population will be 200 million people. We cannot have our beefsteak and our calories unless we have scientific and sound industrial management of our food supply.

The processing and manufacturing of foods for the consumer have become largely the responsibility of the food industry. It has grown to be a 60 billion dollar business. This great growth is based on the application of science and engineering to agriculture and industrial production.

The changes and developments bring their own problems. Scientific studies made years ago showed that our processed foods were often lacking in nutritional factors, or that contamination, decay, oxidation, heat and age had made them unacceptable or of limited value as food. The processing problems involved in manufacturing or processing 80 million barrels of flour, billions of pounds of meat, milk, cheese, canned foods, frozen and dried eggs, and baked goods stagger the imagination. Nutritional values cannot be neglected. Sanitary standards must be high and continually improving. The technologist extends our food supply by means of canning, freezing, dehydrating, and milling, thus preventing loss of perishable foods. He further extends the use of many foods by preventing rancidity, oxidation, decay, destruction by pests, staling, browning, fermentation, rusting of containers, souring, and invasion of pathogens. By proper packaging and storage as practiced today, food can be preserved without loss of nutritional value or consumer appeal. When the manufacturer adds a chemical to a food product, he should have an extensive background of research indicating that no hazard is involved.

The primary producer of food must insure to our gigantic food industry, on which 160 million people depend for their daily food supply, a continuous flow of high grade, uniform products, at an annual level of production which does not fluctuate too greatly. This coordination between agriculture and industry is a tremendous achievement. It involves agriculture, experiment stations, government agencies, medical men, scientific institutions, industries, business genius and organization. Technically and scientifically the scope is beyond any one man's comprehension. New and

and useful scientific ideas are given application as promptly as reduction to practice can be effected.

The food industry has long been conscious of its responsibilities in connection with sanitary problems involved in food processing and manufacturing. It has also become aware recently that some types of processing and manufacturing lower the content of certain factors in the diet which are of prime importance in nutrition, namely, vitamins and amino acids. There are also losses of minerals and carbohydrates during certain types of processing. This newer knowledge of nutrition has opened up vast fields of activity for the food industry.

Scientific investigations have multiplied our knowledge at an accelerated rate, with efforts on the part of industry to meet its ever increasing responsibilities. Industry has put science to work on a magnificent scale to study the means of sanitary processing whereby sterile or pure foods are produced without the occurrence of great losses of valuable ingredients. Processed and manufactured food is thus made effective when used in the diet.

As science entered the growing food industries, investigators and technologists found that many processes and manufacturing operations were difficult to carry out under factory conditions. A new era began with the introduction of chemicals to facilitate processing, to prevent perishable products from deteriorating, to improve stability or nutritive properties, or to replace valuable constituents lost in processing or nonexistent in the manufactured product, but needed from a nutritive point of view, such as vitamin A in margarine. Chemicals cut down marketing losses, as witness the antioxidants that preserve the shortening in cookies, bread, cakes, doughnuts, and other foods. Chemicals may prevent destruction of valuable nutritive constituents such as vitamins, and improve consumer acceptance.

What is a Chemical Additive?

In processing foods or packaging them, chemicals of known composition may be incorporated because of their functional value. These chemicals may be described as "additives¹⁰." When additives are introduced to preserve or improve the quality of the product, they are known as "intentional additives." They are usually added in carefully controlled amounts during processing, packaging, or storage to perform a specific function. Such materials as vitamins for enriching bread, mold inhibitors, bactericides, emulsifiers, minerals, food color, synthetic flavors, and sweeteners are intentional additives. A chemical additive may be nutritive or non-nutritive.

In addition to the intentional additives, other chemical additives may be present in traces in foods when they are marketed. These are known as "incidental additives." For example, salt may be present as the result

of blanching of the food with salt water. Pesticides used during the production of crops may be present in extremely small quantities within tolerance levels on the raw foods. These residues may be removed during processing.

The Use of Chemical Additives from the Standpoint of the Industrial Technologist in Industry

The manufacturer and processor of foods in America accepts a terrific challenge for he assumes responsibility for quality, purity, food flavor and aroma, uniformity, market acceptability, and cognizance of new and varying consumer demands. The technologist and production manager are the individuals on whom many of these responsibilities are placed. The need for good basic training in the fundamental sciences is evident. Men, well trained, will not usually subscribe to untried and doubtful procedures or to the use of unproved chemicals or to the substitution of adulterated or cheaper materials for approved products. The fine spirit in which the well organized manufacturers and processors constituting the food industry conduct their operations has been an inspiration and example to the world. However, we must realize that the very great advances in technical sciences give opportunity to the racketeer to use his skill in defying the law, and it is also evident that some men who are faced with the competition of the alert and expanding technology of competitors find it difficult to meet the demands, and thereby, finding themselves under pressure, may fall into the class whose practices are doubtful.

The food industry has been progressive in its attempts to improve the nutritive quality and to obtain consumer acceptance of foods. We have had over ten years of bread enrichment. The acceptance of this method of improving foods is excellent¹¹. As a public health measure it ranks as one of the foremost. It has been accepted by the Food and Drug Administration, public health authorities, and medical men. This procedure offers a means of combating nutritional deficiencies on a national scale and with nearly 100 per cent coverage.

The fortification of margarine with vitamin A is another public health measure of great importance. Nearly 50 per cent of the consumption of spreads for bread, rolls, and batter cakes now consists of margarine. Recently a number of manufacturers have placed on the market a margarine fortified with 2000 U.S.P. units of vitamin D. The margarine manufacturers state that many former consumers of butter have recently begun to use margarine. Until recently they relied wholly on butter which contained variable amounts of vitamin D. Consequently, margarine manufacturers feel that there is justification for the addition of vitamin D at levels equivalent to the best summer butter. The use of high melting fats in the produc-

tion of margarine, suitable antioxidants, and the addition of color have, with the addition of vitamins A and D, produced a product practically equal to butter nutritionally and functionally.

During the last two years many of the large bakers fortified bread with vitamin D. Varying levels have been used, but the additions have been confined to levels within the range of those given for optional ingredients in the bread standards. While the requirements of vitamin D for infants and children are fairly well known, we do not know whether the amounts ingested from foods such as vitamin D milk and margarine are sufficient to meet the minimum requirements in certain communities. The effect of sunlight is not readily measurable. Consequently, sunlight cannot be relied on for control of deficiencies.

The application of chemical knowledge to improve shortenings is a splendid illustration of the value of technology responding freely and efficiently to the needs of the consumer. Lard, for example, was nearly driven from the market for many years, following World War I. It did not recover its place until World War II when better processing, blending, and the use of antioxidants made lard stable against oxidation. Excellent plastic qualities and food flavor were developed. It also possesses superior shortening value.

The use of calcium salts in bread has been mentioned. It is generally accepted that our diets are low in calcium. Consequently, suitable additions of calcium to certain food products may be in the public interest.

To maintain the integrity of the slices during the baking of apple pie is one of the many problems of the pie baker in connection with the use of apples. He is able to do so with Baldwin and Northern Spy apples but not with McIntosh. The use of calcium salts toughens the tissue so that the slices of McIntosh remain intact during baking. This improves the eating quality and consumer appeal.

A number of important applications of some additives may be listed briefly^{12, 93}.

1. The use of ascorbic acid to prevent browning of fruits following blanching, and to protect the flavor of fruit juices.

2. The addition of sulfur dioxide to prevent discoloration of dried apricots and apples.

3. Additions of emulsifiers to shortening to improve the leavening and shortening power of these important ingredients in bread, cakes, rolls, et cetera.

4. The improvement of shortening for doughnut mixes by additions of fatty acids to the shortening.

5. Calcium and sodium propionate have been found useful in combating molds on bread and cakes.

6. The use of acetic acid and diacetate compounds for preventing mold growth in bread and cakes and to control roe in bread.

7. The addition of chlorine to drinking water supplies to destroy pathogenic organisms.

8. Stabilization of shortening by means of various antioxidants.

9. The use of humectants, such as glycerol and sorbitol, in conditioning foods.

10. During the processing of condensed and evaporated milk citrates and phosphates may be added to prevent curdling and precipitation.

11. Quick setting gelatin can be obtained by use of citric, tartaric, or fumaric acid. These acids are also used to acidify various food products.

12. Leavening action may be produced in cereal products by tartaric acid, fumaric acid, acid phosphates, and pyrophosphates reacting with sodium bicarbonate.

13. The waxing of citrus fruits to promote better keeping quality and more attractive appearance has been practiced.

14. The addition of iron to cereals to prevent anemia, and iodine to salt to protect the consumer from goiter.

15. The use of antibiotics in feeding farm animals, such as chickens and pigs, in preparation for early marketing.

16. A short time method for the production of bacon by introducing the cure into each slab of meat through many injectors, followed by immersion in brine for 24 hours. Nitrates and nitrites are used in curing and preserving meats.

17. The addition of lecithin and various emulsifiers to margarine to improve consistency and emulsifying action, and to prevent leakage and splattering on frying.

18. Recently sorbic acid has been developed as mold inhibitor for use in protecting margarine and other foods. It is applied to the wrapper in which the margarine is marketed.

19. Artificial sweeteners are being used to produce low calorie canned fruits for patients on special diets. Selected diets may also contain artificial sweeteners to replace sugar.

20. The addition of lysine and methionine to improve the biological value of cereal proteins.

21. The use of monosodium glutamate in intensifying flavors of soups, meats, and sauces has received increasing interest on the part of the American housewife.

22. The removal of certain fatty acids and the additions of glycerides of certain fatty acids to give special properties to fats.

23. Calcium salts have been used in canning tomatoes and in processing sliced frozen apples.

24. The use of oxidants in aging flour.
25. Use of calcium or sodium phosphate to inhibit mold growth in cheese. Phosphates are also used to condition processed cheese.
26. Use of phosphates in promoting free flowing salt.
27. Ascorbic acid is being used in processing certain types of meat and sausage.
28. Triethyl citrate has been proposed for use in processing dried eggs.
29. Antioxidant treatment for bacon using butylated hydroxyanisol.
30. Fluoridation of drinking water to prevent caries¹³.
31. Use of alkali in maintaining the green color of canned peas.
32. The acetylation of fats—not used commercially.
33. Sodium carboxymethyl cellulose is used in salad dressings and as a thickener.

This list could be greatly extended, but the examples given illustrate some of the technological uses of chemicals in connection with problems confronting the food industry. In some instances chemicals were used before their effect on humans was well known. Coumarin was used as a flavoring agent for many years, but was recently found to be toxic in high concentrations—higher than ordinarily used. Monochloroacetic acid was used in beer and orangeade in a few instances and was found by the Food and Drug Administration to be toxic, and its use was promptly discontinued. Boric acid is no longer permitted in foods. Other cases might be cited, but in general excellent control has been exercised.

Residues Derived from Pesticides in Food

The use of pesticides to control the production of food is well known. This subject will be mentioned briefly in order to relate the use of pesticide chemicals to the problems involved in processing or in improving the nutritive or consumer acceptance value of food. Pesticides indirectly affect foods because in many instances foods would not be normal in physical appearance, in quality, and in chemical composition if pesticides were not employed, and the amount of food available would be far below the amounts produced today.

The technologist has the problem of removing pesticide residues from foods. Levels of safety must be established, and analytical procedures of a high degree of accuracy must be developed to insure detection and to enable the producer to maintain levels below those involving hazards. The large number of new pesticides developed each year and the wide variety of pests, each group necessitating a specific type of pesticide, make it necessary for the food technologist to devote some of his activities to the development of an adequate control for his products. In many instances toxicological and pharmacological studies are involved, and consumer acceptance studies

must be undertaken if flavor changes due to the use of pesticides occur. Congress has recently passed a bill³⁶ to regulate the levels of pesticides remaining on fruit and vegetables sold on the market.

Technological Problems

The technological problems inherent in the food industry as it faces the complicated demands of government, the consumer, and the exigencies of industrial development are varied and complex. Industry is often at the mercy of a depressed economy, and in some cases it is hampered by lack of adequate developments of the supporting industries. For example, stainless steel filled a great need in the food industry but was many years in developing. The technologist must assist his industry in maintaining the confidence of the consumer in the food products his industry distributes. The food manufacturer is thus obligated to show that the additive or pesticide has a useful function; that it will not make a food appear better when intrinsically it is less valuable; that its use is in the public interest. He should also know that the consumer prefers the treated food.

Establishing the Safety of Foods

The technologist and toxicologist must establish the safety of the product if any physiological reaction is involved in the use of the additive. He must establish, as well as present procedures permit, the noninjurious character of the additive at the levels used or likely to be used in the specific food product under consideration, and should transmit this information to the Food and Drug Administration. It is also necessary to develop and make available the analytical and physiological methods that are employed in detecting and controlling levels in the food product. It is desirable, regardless of the legal requirements of government, to inform and educate the public in connection with any changes or developments covering the marketing of a new food product, or of a conventional product which has been modified by the inclusion of additives.

Many Technological Problems Involved in Manufacturing New Products

The development of new products is usually followed by difficulties when reduction to practice takes place. Many of the products developed during and after World War II were difficult to prepare and necessitated the use of certain additives. A few examples will be mentioned.

The outbreak of World War II was followed, as in World War I, by shortages of certain food products and packaging materials. The substitution of certain food products, such as egg substitutes, artificial sweeteners, coffee extenders, the lowering of meat content of sausages, reduction of

fat content of "ice cream" below legal standards, appeared¹⁴. Attempts were made to have the Department of Agriculture and the Food Board approve the addition, by bakers, of 6 to 10 per cent of soyabean flour to bread flour for bread making.

The opportunity for substitutes and the acceptance of them by the consumer during war time encouraged practices which tended to persist when foods became plentiful. In addition, during war, the food industry faced many new production problems. New products had to be developed to meet the demands of the armed forces; consumer demands changed; shortage of packaging materials compelled the manufacturer, when supplying civilian needs, to change to inferior packages which were in many instances not moisture and gas proof. Technologists showed that many products required vacuum packaging and dehydration to a low water content. Thus new types of processing and preservation were necessary. Dried eggs had to be reduced to 2 per cent moisture or less, and the sugar removed from the whites. Moisture and gas-proof containers had to be provided, and nitrogen or carbon dioxide added to the evacuated product before cans were sealed.

Active dry yeast developed as a product for the army had to be reduced to 7 per cent moisture and packed in sealed tins. The enrichment of bread and margarine introduced chemicals into basic foods having wide distribution. Emulsifiers became more important in cake, rolls, and bread making. Housewives were busy in factories and office, and baking at home was largely discontinued. The better quality cakes produced by the baker with the aid of emulsifiers were far more acceptable than cakes without emulsifiers, and the baker greatly increased his percentage of the total cake market.

After the war, prepared mixes became widely used, and many technological problems were involved in their preparation and stabilization. Other examples where chemicals are employed might be cited, but the cases presented illustrate the wide range and the type of problems which the technologist and the manufacturer must solve.

The Attitude of the Food and Drug Administration toward Additives

The Food and Drug Administration is responsible for the administration of the Federal laws pertaining to food. Laxity and lack of morale in the administration of the law would be reflected in transgression of the food laws by irresponsible elements. It has been our good fortune to have men of high character and integrity in charge of the administration of the food law since its inception in 1906. They have realized their responsibilities to the public, but they have also shown their willingness to cooperate with

industry in a constructive manner. They have been progressive and adjusted their ideas to the changing scientific and economic developments.

The point of view of the Food and Drug Administration is of primary importance to the technologist in the food industry as well as to industrial management. While the Administration must look at every problem from the standpoint of control, it has shown vision in the progressive attitude it has taken in cooperating with industry and in assisting in the development of new products. A number of addresses by Commissioners Dunbar and Crawford are indicative of the attitude they have taken in connection with the use of chemicals in foods.

Dunbar¹⁵ is concerned about the aims of some manufacturers. Is too much stress being put on the attempts to "medicate" foods? He believes the tendency to make nutritional or therapeutic claims for foods may have been overdone. The American consumer is vitally concerned with his food supply. He desires to have it free from harmful or potentially harmful substances.

Dunbar¹⁶ was careful to point out that he favored the nutritive improvement of basic foods that needed attention, such as the addition of vitamin D to milk, and the vitamin enrichment of bread. It was a sound advance and in the public interest. The American public is concerned about deficiencies in what it believes to be essential ingredients. Dunbar¹⁵ does not believe nonnutritive ingredients should be added to any food product unless the addition serves some useful purpose.

Industry should find out what the consumer wants and should revise its production to meet consumer demand and to regain consumer confidence. Dunbar also believes that industry should carry on a vigorous campaign to counteract the nutrition quack who is spreading misinformation about foods. The food industry in general, he states "is aware of its obligations and takes adequate precautions to undertake suitable toxicological studies before using chemical substances in food."

He believes that the food industry should support sound legislation to prevent the use in foods of chemicals untested for safety or serving no definitely useful purpose. He adds, "Don't misunderstand me. I am a chemist and I know that many of the products of the chemical industry vastly improve the nutritive value and palatability of foods. I note that the label of a very popular brand of rolls made with unbleached flour carried a sodium propionate declaration. This suggests that the consumer is not necessarily offended by the use of a chemical that serves a useful purpose and is wholly without public health significance."

He suggests two tests which should be applied to any proposed addition. First, is it completely harmless? Second, does it serve a truly useful purpose from the consumer standpoint?

In his testimony before the Delaney Committee he stated his views on

additions: "I feel that no new chemical or no chemical that is subject to any question as to safety should be employed until its possible injurious effect, both on an acute and on a long term chronic basis has been shown to be nonexistent. In other words any chemical that is proposed for use ought to be proved in advance of distribution in a food product to be utterly and completely without the possibility of human injury."

Crawford¹⁷ has called attention to the quackery that exists in the field of nutrition. American industry has given us an excellent food supply, and the diet of the American people has improved as the result of synthetic chemistry which enabled bakers to enrich our bread. The canning and freezing of foods have developed so that the nutritional properties of foods are retained. However, there is a fringe of food quacks in the fields of nutrition and medicine that cannot be dealt with adequately by law since it is largely an educational problem. Nutrition education should emphasize the distinction between known facts and speculations.

He also states, "Another limitation to consumer protection and one which can be dealt with through legislative enactment is the absence in existing law of authority properly to regulate the use of food additives some of which may be harmful or otherwise contrary to consumer interest.

"There is an interesting and significant connection between this problem and that of quackery. The growing use of food ingredients with strange chemical names has provided the promoters of food faddism with some rather effective ammunition. Frequently we see this reflected in our correspondence with consumers who are interested in problems of diet. Many are seriously concerned about the chemicalizing of our food supply. Whatever the source of their information, or misinformation, on this subject, their concern is real.

"The growing use of food additives has emphasized a serious gap in consumer protection under the Federal Food Drug and Cosmetic Act. The law as passed in 1938 requires premarketing tests of new drugs to insure their safety when used as directed, but it does not require testing of new food additives before they are used. While the authority to prescribe food standards may be exercised to exclude additives whose safety is suspect, the prescribing of standards for each food is a slow process, and is not an effective solution of the problem. Under the law as it now stands, an ingredient of questionable safety may continue to be used in food until such time as standards can be formulated and become effective or until we have sufficient evidence to prove that it is poisonous or deleterious. This may take years, during which the public may be used as guinea pigs. I am glad to say that most food manufacturers do establish the safety of new ingredients before using them. But there are some who do not."

The Food and Drug Administration advised Congress in hearings before

the Delaney Committee that there is need for legislation to require adequate testing of these new ingredients of foods. The Delaney Committee after hearings covering a period of two years recommended that new legislation covering chemicals in foods be drafted.

"It is a disturbing fact, however," Crawford continues, "that some of the additives now in use have not been adequately studied by our newer methods. Other substances now in use in significant amounts have been tested and shown safe by all available methods that are reasonably applicable. They would be considered harmless under any standards likely to be written into law. But are these widely accepted methods entirely adequate? Are they delicate enough, are they precise enough to insure that the safety and nutritional values of these foods are not impaired? Can we sharpen the accuracy of our translation of the results of animal experiments into potential effects on humans? Can we derive more information from human tests—which have necessarily been of limited scope and duration—about the effects of these treated foods when consumed over the span of normal human life?

"I do not mean that we should cease our efforts to improve the quantity and quality of our foods through the use of new substances. Hazards in some degree are inherent in all progress. I do mean to suggest that you who are so vitally interested in the integrity of our food supply will serve our nation well if you keep close watch on these newly admitted additives as they are tested in the laboratory of human experience during the years ahead. Our present abundant food supply is the safest and most nutritious in history. Let us remain vigilant to avoid any decline."

We cannot rely on natural foods as the *sine qua non* of purity. DeEds¹⁸ has pointed out that spinach and rhubarb contain oxalic acid, a fairly toxic substance; cabbage contains a goitrogenic substance; potatoes contain solanin; wheats in certain areas of South Dakota contain selenium in amounts that make the wheat unsafe for food. Consequently, we are justified in not accepting the natural foods as necessarily the ultimate standard when evaluating food products. Wilson and DeEds¹⁹ call attention to the importance of diet in studies of chronic toxicity. Certain diets accentuate the toxicity of the test substance.

Williams²⁰ and his committee have considered the role of standards in respect to the possible restriction on research in the food industry. They proposed that standards be promulgated without prior hearings when no controversy arises. A bill, H.R. 6434³⁸, embodying these proposals has recently been passed by Congress and signed by the President.

Determining the Toxicity of Additives

The Food Protection Committee has defined a number of terms that are frequently used and are of fundamental importance in any discussion of

chemical additives. Toxicity is the capacity of a substance to produce harm. Hazard is the probability that injury will result from the use of the substance in the quantity and in the manner proposed. The statement of the Food Protection Committee "Safe Use of Chemical Additives in Foods", 1952, (pp. 845-847) should be consulted for information on basic principles and procedures in determining the safety of chemical additives.

An article by Brennan²¹ is of interest as an index of the type of experimental work required to carry on a toxicological study. This study was designed to cover pesticides and food additives. The discussion by one trained in food law is timely since chemicals are recognized as useful and necessary in modern food processing, but some of the procedures recommended for determining the toxicological effects of chemicals have not been widely accepted.

The nature of the information which should be made available to the body charged with rendering a decision on the question of safety of an additive for use is discussed. "The proponent of the chemical should present detailed reports of laboratory and possibly clinical investigations, establishing the chemical nature and properties of the proposed additives and showing the physiological response of animals and of man to the ingestion of the proposed chemical additive." The physical and chemical properties of the additive should be made known.

The second phase of the investigation according to Brennan should cover the acute toxicity of the chemical proposed for use. The acute toxicity test is usually expressed as the LD₅₀ (minimum lethal dose) which is the dosage that will destroy one half the animals in a given period of time. This test enables one to quickly eliminate highly toxic substances. In carrying out the acute toxicity tests the chemical should be administered orally and intravenously. The extent and rate of intestinal absorption can be determined. The animals used should be young adults of both sexes and should be used in large enough number to permit the estimation of the LD₅₀ within a margin of error of 20 per cent or less. The use of at least six groups of ten animals each has been found effective.

The type of diets for subacute and chronic toxicity studies he states has been given extensive study. Fundamentally, these studies involve the feeding of diets including the chemical additive over a protracted period of time. In the subacute studies the animals are fed at three or more dietary levels over a period of about two to four months. The groups generally consisting of 10 males and 10 females may be fed as follows:

1. The control group given the diet without the additive.
2. A low dosage level group fed a diet in which the chemical is present in an amount about ten times the level at which it will be used in food.
3. A maximum tolerance level group; the diet in this case contains the highest level that the animal can tolerate.

4. A group with a diet containing the additive in amounts intermediate between the groups 2 and 3.

During this experiment the investigator will observe the growth, mortality and rate of food consumption. He will make blood counts and quantitative urine analyses. At the end of the study the animals are autopsied, organ size and character of the organ are noted, and histopathological studies will be made. While these experiments are underway, a study on another species, such as dogs, may be carried out.

These subacute studies will establish the toxic level of the chemical additive and in addition the toxic responses and the kind of organs and tissues affected. If the chemical is highly toxic, it will be discarded. The studies will also provide data for the levels to be used in chronic studies.

The type of chronic toxicity studies best suited for foods is a matter of controversy. If the lowest level of the additive in the subacute toxicity test has not produced harmful effects in the rat or other test species, the compound may be safe for use in foods. However, to prove the safety of the additive over the life period of the animal, two sets of long term feeding studies are undertaken; one test will cover a year, and the other, the life span of a particular species, usually rats, which have a life span of about two years.

In the long term experiments at least four groups of animals should be used, each containing 10 males and 10 females. The animals are fed at the following levels:

1. A control group which does not have the chemical additive.
2. A group on a diet similar to the control but containing the chemical additive estimated 100 times the proposed level of use.
3. A group whose diets contain the additive at the highest tolerated dose.
4. A group with the additive added at a level midway between 2 and 3.

One-year feeding experiments should be set up at similar levels and with similar methods, and carried out on three other species of animals. Urine analysis and blood studies should be made during the experiment. The rate of growth, mortality, food consumption, reproduction, changes in organ weight, histopathology and tissue analyses should be followed.

Reproduction studies are carried out on the four dietary level groups to the third generation. The third generation is sacrificed at 21 days and autopsied. The parent generation is sacrificed and studied after the second generation is weaned.

It is important he points out that in case of diets where the additive consists of a large per cent of the diet, consumed over a life time, that pathological studies should be made on several species. All experimental and control animals are sacrificed and autopsied and microscopic section and examination made of all the major organs and tissues, and where effects

on organs and tissues are found, the lowest level at which harm is produced must be determined. The data must be correlated and studied by experts.

Clinical investigations may be desirable. It is often necessary to determine the effect of the additive on the human system. Control groups should be used and every subject should be free from complicating factors. Regular physical and laboratory examination should be made on each test subject. The studies should be made on sufficient numbers to be statistically significant.

The Food and Drug Administration has developed a number of methods for determining toxicity of foods. The published papers of W. B. White²² and that by A. J. Lehman²³ describe methods and procedures which established fundamental patterns. They advocate the use of acute toxicity studies and also chronic toxicity studies covering the life time of the animal. At least three species of animals should be used. Reproduction studies should also be carried on.

Herrmann²⁴ points out that a new food additive, tested by all methods reasonably applicable and if no adverse results are obtained, should be cleared for use. However, its use should be followed carefully. The following investigations he believes would constitute a minimum in judging the safety of a new chemical additive:

1. Establishment of the chemical identity and analytical methods of detection, identification, and quantitative estimation of the proposed chemical additive.
2. Investigation of acute toxicity in test animals which should not be limited to rodent species, but should include also one or more nonrodent species.
3. Study of subacute and chronic toxicity effects, including not only growth, mortality, and reproduction patterns, but also blood level studies, metabolic fate of the compound, examination of organs and tissues, and similar criteria.

Several investigators have given thought to setting up procedures for carrying on toxicological tests in connection with the use of products in foods that may involve potential harm. It should be pointed out that the procedures used in testing the toxicity of drugs may not necessarily apply to foods. This has not been clearly understood, but it should be strongly emphasized.

Heyroth²⁵ stated that the current practice in evaluating chronic toxicity of a pesticide consists in incorporating it in various proportions in the food supplied to groups of animals of various species for periods up to their total life span. The rates of growth, utilization of food, fecundity and mortality, the weights and histopathologic appearance of the organs are observed. By the use of appropriate analytical methods, its rate of excretion,

the sites, extent and duration of storage in the tissues, and its metabolic fate may be learned. Utilization of such data in evaluating the hazards to man from the use of a new pesticide involves much uncertainty, especially if the response in different species varies, and if species become resistant. To overcome this uncertainty, the employment of human experimentation of the types formerly conducted during the existence of the Remsen Referee Board of Consulting Experts is suggested. Large scale experiments in connection with the use of fluoride in drinking water provide a pattern for determining optimal concentration and use of a chemical.

The toxicological procedures employed in pesticide evaluation are, in general, based on the procedures used for evaluating the toxicity of chemicals regardless of the end use of the material. The emphasis and scope of the procedures are matters of individual consideration in the case of each specific chemical. To be of most value, the toxicological tests should be contemporaneous with the developmental studies of the compound. If the substance shows promise, further studies are undertaken and its potentialities fully explored. Hazelton^{26, 27} states we finally reach a stage wherein investigations on the mechanism of action, antidotes, excretion or other fate in the body, accumulated potentials, specific hazards in application, methods of removal, levels found in consumer's food and levels at which substances in foods become a health hazard can be evaluated.

Horsfall²⁸ pointed out that chemically one cannot differentiate among various samples of copper oxide. Fungi in the presence of various oxides will show marked differences in growth. Zinc ethylenebisdithiocarbamate and zinc dimethyldithiocarbamate cannot be differentiated chemically; they can be differentiated by biological means.

Culver²⁹ gave emulsifiers of the polyoxyethylene type to human patients. He found no evidence of toxic reactions at the levels fed in his experiments.

Deuel³⁰ describes the tests employed in the evaluation of the safety of food additives. Minimum toxicological tests consist of:

(a) The determination of LD₅₀ of the chemical being examined is carried out on one species and confirmed on a second species of animals. Suitable control experiments should be instituted to determine whether or not mere bulk of material fed causes toxic reaction.

(b) Acute tests are usually carried out over a period of six weeks; the test material is included in the basal diet at several levels. One observes the symptoms and examines animals in case death occurs. Acute tests are used to determine the levels to employ in the chronic tests. Acute tests should be carried out on at least three species, one of which is a nonrodent. Test dogs are usually considered essential.

(c) Chronic tests. These are considered generally the most important. They are usually continued for two years and in the case of rats are usually

longevity tests. All tissues are removed at the end of the test for histopathological examination. One must know how to differentiate between old age and the effect of the additive.

(d) A modification of the longevity test which provides more information during the same period of time is the multigeneration technic.

(e) Determinations are made of any toxicity which may develop in the foods containing the additive as a result of conditions to which the food containing the test substance may be subjected.

(f) The most important fact to establish in such a series of tests is that the product used in the tests is what it is stated to be.

Metabolic Testing of Additives. This method of testing should cover the rate of absorption, the effect on the digestibility of foodstuffs, and the mechanism of oxidation or removal from the body. Deuel³⁰ states "In cases in which a biological and metabolic approach are possible, the proof of harmlessness of a food additive can be established more quickly, more cheaply, and on a more sound scientific basis than is possible with the present toxicological approach." In cases where the chemical nature is not known, nor the metabolic pathology, the present methods of testing must be continued.

Chemicals in Foods and Some Reactions by Congress and the Public

The use of chemicals in the food industry as functional ingredients, in the United States and Great Britain, has produced some misunderstanding, but in general the consumer felt satisfied that his food was honestly and technologically well prepared. So-called science writers who had little or no understanding of the technological processes used in the food industry wrote extravagant articles for the daily papers and popular magazines with the result that some individuals became uneasy and their confidence in the food industry was disturbed. The majority of consumers, however, retained full confidence in the food industry.

Congress in 1950 appointed a committee, the Delaney Committee, to investigate the use of chemicals in foods. The resolution, H.R. 323, 81st Congress, 1st Session, June 20, 1950³¹, authorized and directed the Committee to conduct a full and complete investigation of the following:

"1. The nature, extent, and effect of the use of chemicals, compounds, and synthetics in the production, processing, preparation, and packaging of food products to determine the effect of the use of such chemicals, compounds, and synthetics (a) upon the health and welfare of the Nation, and (b) upon the stability and well-being of our agricultural economy;

"2. The nature, extent, and effect of the use of pesticides and insecticides with respect to food and food products, particularly the effect of such use of pesticides and insecticides upon the health and welfare of the consumer

by reason of toxic residues remaining on such food and food products as a result of such use;

"3. The nature, effect, and extent of the use of chemicals, compounds, and synthetics in the manufacture of fertilizer, particularly the effect of such use of chemicals, compounds, and synthetics upon (A) the condition of the soil as a result of the use of such fertilizer, (B) the quantity and quality of the vegetation growing from such soil, (C) the health of animals consuming such vegetation, (D) the quantity and quality of food produced from such soil, and (E) the public health and welfare generally."

A full report of the Hearings before the House Select Committee to Investigate the Use of Chemicals in Food Products is given in H.R. 323, 82nd Congress, 2nd Session, and in Investigation of the Use of Chemicals in Foods and Cosmetics, Union Calendar No. 743, H.R. Report¹ 2356, 82nd Congress, 2nd Session.

The Delaney Committee issued a report signed by five members of the committee of six. A minority report filed by Congressman Walt Horan, a member of this Committee, and two reports covering additional views were submitted and published with the majority report of the Committee. The report covers the following subjects:

I. Introduction: Statement on the creation of the Committee and the scope of the investigation as given in the opening paragraphs, 1, 2, and 3.

II. Nature and Scope of the Problem: This section describes the nature of some of the production problems; mentions the use of chemicals in enriched foods, the application of science to processing as a necessary part of our economy and the possible involvement of chemicals which have not been thoroughly explored. The food industry and chemical industry have shown a high degree of responsibility, and the record in the food industry is excellent. There are a few chemicals which are inadequately tested: "In addition, although many chemicals, as already indicated, serve a useful purpose to the consumer, others do not and may in fact conceal inferiority, adversely affect the nutritive value of the foods in which they are employed, or act as substitutes for nutritious ingredients⁸.

"The committee wishes to point out that the United States Food and Drug Administration, the United States Public Health Service, the United States Department of Agriculture, as well as comparable State agencies, industry and colleges and universities, are devoting considerable time and sums of money to research and experimental work for the purpose of obtaining solutions to these problems."

III. The Use of Chemicals in the Production, Processing, Preservation, and Packaging of Foods: A number of chemical compounds are discussed from the standpoint of their use such as nitrogen trichloride, thiourea, para-phenetyl urea, lithium chloride, mineral oil, monochloroacetic acid,

dehydroacetic acid, emulsifiers, and hormones in food production, such as diethylstilbestrol, and estrogen used in milk production.

IV. The Use of Pesticides: DDT, chlordane, selenium, phenylmercury compounds, benzene hexachloride, and a number of other pesticides are given consideration because of the danger of harmful residues. In some cases there are no simple tests available for the detection of the specific pesticides used in protecting the food during the growing period.

V. The Use of Chemical Emulsifiers to Replace Natural Food Substances in Baked Goods: This section covers discussions of formulas and the possibility that replacement of natural products, such as eggs and shortening by chemical emulsifiers, may take place.

VI. Inadequacy of present legislation: Suggestions for changing the present Food and Drug Law to give the Food and Drug Administration more control over the introduction of new chemicals into food products. Pretesting of chemicals to insure their harmlessness is advocated by some of the witnesses. The present law is considered inadequate by some of the witnesses, and a number of witnesses advocated that a section generally similar to the new drug section of the Federal Food, Drug, and Cosmetic Act be added to the statute. Several witnesses suggested that an advisory board be appointed to assist the Food and Drug Administration in determining the safety of a chemical proposed for use as a food product. There are at present no provisions in the food laws of the Federal Food, Drug, and Cosmetic Act comparable to the new drug section. Section 402 (a) (1) declares a food to be adulterated if it bears or contains any poisonous or deleterious substance which may render it injurious to health. This provision places the burden of proof that a chemical added to food is harmful on the Food and Drug Administration. In some cases the Food and Drug Administration does not have the necessary proof of hazard, although the product may be one of doubtful safety. The Food and Drug Administration may secure necessary proof to bar the use of a deleterious, harmful substance, but this may take considerable time and effort.

VII. Conclusions and Recommendations: The increasing use of chemical additives in the production, processing, preservation, and packaging of food has created a serious public-health problem. The evidence presented reveals that existing Federal laws do not provide complete protection to the public against the addition of chemicals which may be unsafe.

"The strong recommendation of most of the witnesses before the committee was that no chemical should be permitted entry into the Nation's food supply until its safety for use has been demonstrated beyond a reasonable doubt. A provision in the law to that effect would benefit the food and chemical industries as well as the consuming public⁹³. Thus the Director

of the Bureau of Nutrition of the Department of Health of New York City told the committee:

'I would think that the industry, meaning the chemical industry or food industry in general, would welcome an outside authority, a nonprejudiced outside authority, to pass judgment upon the adequacy of safety tests that responsible members of industry itself use before they apply it to food. Certainly the chemists and scientists in these organizations can be put under tremendous pressure by management and many of them, I am sure, would welcome the final judgment of an outside source whether or not the addition of a new chemical may or may not constitute a health hazard (94).'

"In the committee's view, it is important that unnecessary obstacles to technological improvements in food production and processing not be created. It is believed that a "chemicals in food" amendment to the Federal Food, Drug, and Cosmetic Act would not hamper scientific improvement in this field, but rather would stimulate research, aid in technological improvement, and redound to the benefit of the food and chemical industries. It is interesting to observe, in this connection, that the New Drug Section has given new impetus to pharmaceutical research, and new strength to the ties between drug manufacturers and medical research facilities outside the industry.

"It is clear that before a chemical is used in or on a food, or as a food, it should be subjected to acute and chronic toxicity testing to insure, as far as possible, that the public health will not be endangered. It is not possible to delineate, in any legislation, the specific methods or conditions of testing which should be performed on any chemical or class of chemicals. The specific type and duration of tests necessary to insure the protection of the public health will vary, depending on the composition of the chemical and the food involved, the breakdown products of the chemical and food when brought into contact or intermingled, the metabolic fate of the chemical, the quantity of the chemical or related chemicals already found in the diet, and many other factors. For this reason, your committee recommends that legislation to cope with the chemicals in food problem should not attempt to specify the type and manner of pretesting which should be conducted. Rather, the legislation should provide that evidence that the chemical is safe, and does not produce harmful chemical reactions, in the end food product, should be submitted to the Food and Drug Administration for clearance before the chemical is utilized. In any evaluation of the safety of any proposed chemical, the extent of the use of the chemical, or similar chemicals, in or on other foods, must be taken into consideration.

"It was suggested by some witnesses that any legislation should treat insecticides differently from chemicals which are added to a food product after harvesting. It was contended by these witnesses that insecticides are

not deliberately added to foods as are most other chemicals used for food purposes, and that the amount of the insecticide remaining on the food is not a constant one, as may be the situation in the case of other chemicals. However, insecticides, as well as other chemicals used in the production and processing of food products, are deliberately rather than accidentally utilized to perform a specific function with regard to the food in question. It is true that it is not customarily intended that insecticides appear on the end food product, but under certain conditions, particularly when proper precautions are not taken, they may so appear, in greater or smaller quantity. It is little comfort to the consumer that the manufacturer or supplier did not intend that the insecticide remain on the food product, or at least not in such great quantity.

“It is essential that, before a pesticide is permitted to be used on a food, reliable methods of analysis for the quantitative determination of the chemical be available. Some insecticides were widely used before such information had been obtained, and insecticides are presently being employed for which such methods are not available. The importance of this requirement is obvious. If the quantity of chemical in or on the food cannot be ascertained, it cannot be determined whether or not any hazard is involved. However, only part of the question is answered when the quantity of the particular chemical in the diet is established. This information is meaningless unless the effect this quantity will have on the human body when ingested both for long and short periods of time, and by all segments of the population, is also known. The continued high level of health and vitality of our nation demands that both of these questions be answered regarding any alien material which may find its way, in any amount, into our food supply.

“Your committee recognizes the need for supplemental legislation which will provide more adequate protection to the public. While the committee is in agreement with the opinions expressed by many of the eminent witnesses who testified, that no chemical should be permitted in or on the Nation's food products until its safety for the use for which it is employed has been demonstrated beyond a reasonable doubt, it also recognizes the necessity for the continued use of chemicals in sprays and other insecticides if the Nation is to be supplied with food. In the committee's investigation, which included inspection of the facilities used in the production and processing of a number of the items contributing to the food supply of this Nation, it has been convinced that with proper care, and by taking reasonable precautions, it is possible to utilize the poisonous properties of such chemicals in destroying insects and controlling diseases which attack many crops, without endangering the health of the people who consume these products. The committee does not believe that an insecticide which can be

used without danger to the consuming public, and with benefit to the grower, should be kept from the market because of the failure of a few to observe the recommended directions for use.

"In conclusion, the evidence has convinced your committee that chemicals have been utilized in and on the food supply of the Nation without adequate and sufficient testing of their possible long-range injurious effects; that the public is entitled to greater protection with respect to the foods it must necessarily consume; and that such protection is not afforded by existing legislation, under which the Government may take no action until after the food has been placed upon the market and injury may have occurred. Your committee recommends, therefore, that the Federal Food, Drug, and Cosmetic Act be amended to require that chemicals employed in or on foods be subjected to substantially the same safety requirements as now exist for new drugs and meat products. Adequate provisions for a comprehensive judicial review of administrative decisions should be included in such an amendment."

Respectfully submitted.

JAMES J. DELANEY, New York, *Chairman*

E. H. HEDRICK, West Virginia

PAUL C. JONES, Missouri

A. L. MILLER, Nebraska

GORDON L. McDONOUGH, California

Additional Views on the Use of Chemicals, Estrogenic Hormones, and Pesticides in the Production of Foods. This report was signed by A. L. Miller and Gordon L. McDonough. It covers additional matters. They agree with the full report but believe a fuller discussion is desirable. They discussed chemicals in foods, estrogenic hormones in foods, and pesticides. The position is taken that the food industry in general has taken up its responsibilities effectively, but the present law is defective because it does not require pretesting. The law should be strengthened to protect the public from those concerns which seek short cuts in the production and processing of food. Estrogenic hormones have been recently introduced. There are some dangers the public does not appreciate. Thirty million chickens were treated with hormone pellets in 1951. Mink growers suffered because they fed the heads of chickens so treated to mink and failed to obtain reproduction because the mink became sterile. The whole problem needs more study.

Many pesticides are extremely toxic to humans. The housewife may fail to realize that fruit and vegetable products should be thoroughly washed before they are used. The pesticides purchased for home use may be carelessly used and the fruit or vegetables not properly washed to remove harmful residues prior to use.

A paragraph was added by Congressman G. L. McDonough giving his views on the effective measures taken by the State of California to protect the public.

Minority views: A minority report signed by Walt Horan and another report by Thos. G. Abernethy constitute the minority views. Walt Horan states that the majority report as presently constituted is alarmist and adds nothing to increase production of food, is reactionary and a deterrent to needed progress. "It is one thing to raise the alarm; it is another to put out the fire." Mr. Horan took up the question of emulsifiers. They have not been proved toxic. Any discussion of them has been confined to economic rather than to the question of the effect on the health of individuals. He corrected the statements in the majority report referring to hormones and their use by pointing out that all of the 60,000 pounds of poultry seized were not destroyed, but under Food and Drug Administration inspectors salvage was undertaken. Congressman Horan did not favor the Committee's recommendation for legislation covering the use of hormones in poultry. He does not agree with the majority report on pesticides and objects to the following: "In 1948 the Council on Foods and Nutrition of the American Medical Association declared that the appearance of the new insecticides had created a danger; that there was an appalling lack of factual data concerning the effect of these substances when ingested with food; and that the chronic toxicity to man of most of the newer insecticides was entirely unexplored."

Subsequently, on January 28, 1950, the Council on Foods and Nutrition³² A. M. A. issued a statement which declared in part: "The introduction of numerous synthetic organic pesticides offers promise for increasing the Nation's food supply and improving health through the control of insects and other pests. Past experience, however, indicates that poisons cannot be used safely on food crops without the development of certain fundamental knowledge concerning the poisons. What these materials will do to pests and food crops and to workers who handle them must be known, and there must be developed, also, a knowledge of what these materials will do to warm-blooded animals and when small amounts of residue are incorporated in their foods. Furthermore, practical methods of analysis should be available to permit identification and measurement of residues that may persist on or in consumer products. Such essential information is undeveloped for many of the agricultural poisons now in use "

These paragraphs were presented in 1950 and are no longer completely true. The Department of Agriculture and the Public Health Service are cooperating on methods of analyses and the effects of the chemicals used as pesticides on food crops, on pests, and on the consumer. The Public Health Service has been studying the toxic effects of many of these chem-

icals on man. They have not found "a single case of chronic poisoning due to residue of pesticides chemicals in foods. As new pesticides are developed, much research is needed to establish their toxicity for man, and the Public Health Service should be adequately supported in these essential studies."

Dr. Fred Bishop of the Bureau of Entomology, United States Department of Agriculture, was asked by counsel of the Delaney Committee if he agreed with the following statement: "The Council of Foods and Nutrition of the American Medical Association is acutely aware of the toxicological problems presented by the rapid introduction of synthetic organic pesticides and herbicides. The chemical contamination of foods with residues of these substances is but a part of the broader problem created by their wide use, for in addition to the danger from ingestion, the effects of inhalation and skin absorption must be determined.

"The problem is created by the great number of new pesticides on the market. The appearance of these is creating an increasing volume of inquiries at association headquarters. That danger exists is evidenced by the appalling lack of factual data concerning the effect of these substances when ingested with food. The chronic toxicity to man of most of the newer insecticides is entirely unexplored. In fact, the majority are so new that their limitations and even their full scope of usefulness have not been established."

Dr. Bishop replied:

"I believe that is editorial and generalized statement, and I cannot agree with it. 'Entirely unexplored,' I don't believe that anybody else would agree with that either. I am rather surprised that a statement would appear in that journal as sweeping as that."

Congressman Horan sums up his position as follows: "I feel that, by their nature, pesticides should be considered separate from other chemical additives for the following reasons:

"1. Pesticides are necessary and must be used to produce food products and to protect the public health. Their use is from necessity and not by choice. These chemicals are present in varying and minute amounts.

"2. Pesticides are already controlled by a legislative pattern consisting of Federal and State laws and regulations thereunder. These laws are the Federal Insecticide, Fungicide, and Rodenticide Act of 1947, the Food, Drug, and Cosmetic Act of 1938, State laws in 39 States which in general follow the pattern of the Federal Act of 1947.

"The Federal Insecticide, Fungicide, and Rodenticide Act of 1947 requires that before a pesticide can be shipped in interstate commerce, it must be accepted for registration by the United States Department of Agriculture. Registration depends upon a showing that the product is both safe and efficacious for the purposes for which it is to be sold. Supporting data must be made available to the Department before registration is

granted. Lack of data will result in a refusal to register. The type of supporting data depending upon the claims made consist of: entomological efficiency, pathological toxicity, residue at harvest, acute and chronic toxicity data, data showing effect on soils, data showing effect on taste and flavor. The solicitor for the Department of Agriculture has ruled that under the Federal Insecticide, Fungicide, and Rodenticide Act of 1947, necessary data can be required before registration to show that the material is not only efficacious for the uses recommended but that it is safe when used as directed to the spray operator and to the consuming public.

"The Food, Drug, and Cosmetic Act directs the Federal Security Administrator to limit, by regulation, the quantity of added poisonous and deleterious materials, including pesticides, which remain on any food 'to such extent as he finds necessary for the protection of public health.'

"Standard procedure under existing laws before a product is registered is that the United States Department of Agriculture consults with the Food and Drug Administration and the United States Public Health Service. Both of these agencies are fully informed before a product can be sold to interstate commerce and the product is not accepted for registration if, in the opinion of any one of those agencies, it would be detrimental to the public health.

"Under the State laws, similar controls and authority can be exercised at the state level.

"Continued investigation of all phases of the product such as entomological efficiency, pathological toxicity, flavor and taste, effects on soil are continued by the industry, by the United States Department of Agriculture, Bureau of Entomology and Plant Quarantine, Bureau of Plant Industry, State land-grant colleges, the United States Public Health Service, Food and Drug Administration, and the Fish and Wildlife Service. The claims under which the material is registered are reviewed at regular intervals by the Department of Agriculture in the light of any new research data.

"It is common practice in the fresh fruit and vegetable industry to wash products after harvest before shipment. This is because the Food and Drug Administration polices all shipments in interstate commerce. This applies to practically every fresh fruit and vegetable. Investment in washing machinery is one of the heaviest capital items in the fresh fruit and vegetable producing, packing, and shipping business. Use of such equipment insures the removal of spray residue. In addition, washing fresh fruits and vegetables in preparation for retail sale is a growing practice. Thus, washing at both wholesale and retail levels affords protection against the presence of toxic residues. Authority now exists under Federal and State laws to bar from commerce any fresh fruit and vegetable product containing toxic residues which might be injurious to health.

"In California, for example, under standards set by State law, 2,363

samples of produce were analyzed in 1949 and only 110 were found to contain spray residue in excess of State tolerances. Of course, it should be borne in mind that 'tolerances' always err in favor of assurances to the consumer. In 1950, 2,842 samples were analyzed and 103 were found to contain overtolerance amounts; however, the averages and circumstances involved in these cases did not warrant filing criminal complaints. California imports some fruits and vegetables from other States and countries. Analyses of fruits from Oregon, Washington, and Idaho, and of vegetables from Florida, Texas, Arizona, and Mexico during 1950, did not reveal any deleterious residues in excess of legal tolerances.

"The chemical industry, in developing a new pesticide, first screens thousands of chemicals to determine their biological efficiency. If one of the chemicals shows promise, research is immediately started to determine its practicability for use. The toxicological and biological research is started by the producing company. When promise is shown, work is expanded in cooperation with private research institutions, the United States Department of Agriculture, and land-grant colleges. The Food and Drug Administration and the United States Public Health Service are consulted. A recent survey of the industry shows that the cost of research before a product can be registered for sale ranges from \$200,000 to \$400,000.

"The Food, Drug, and Cosmetic Act of 1938 has given the Food and Drug Administration full authority to protect the public from any residue hazards from the use of pesticides through the establishment of tolerances. Since 1938 only one official tolerance has been established, namely, on fluorine. In spite of the fact that tolerance hearings have been held on all of the principal pesticides at which 25,000 pages of technical data on residues and toxicity were presented, the residue tolerance hearings were closed on September 15, 1950, nearly 2 years ago, but no tolerances have yet been issued. Data upon every one of the pesticides referred to in section IV of the committee report were included. The control called for does not await new legislation but administrative action according to the existing law.

"In the light of these facts, it seems unfair to me to state in part II that there are 276 chemicals being used in foods today, the safety of which has not been established.

"This point is again referred to in part VI of the committee report as a basis for new legislation. I feel that the public is entitled to the exact status of the situation.

"If any of these are pesticides, why have the regulations provided for in existing law not been forthcoming in this period of time? As not few (as indicated on p. 20 of the committee's report) but many witnesses testified, we should look to better use of authority already provided before conclud-

ing that additional authority is needed or could be wisely exercised if granted. In this light the total import of part VI of the report is in contradiction with the burden of testimony from witnesses closest to the subject.

"In the final analysis we must designate to some responsible Government agency the determination of that which is or is not deleterious to the public health. We must recognize existing facilities which allow for the licensing of pesticides. Then, having arrived at that point, we must designate the policing agency to maintain a protective procedure so that our consuming public may be assured that what they consume is safe.

"In the Public Health Service, the Department of Agriculture, and the Food and Drug Administration we have responsible agencies. Failure on the part of Congress to recognize their abilities to contribute to orderly progress is a sin of omission we must avoid. Failure in this committee's report to point out, at every turn, the good work of these agencies can leave but a negative conclusion with everyone.

"We need faith in Government. We need both a feeling of security and encouragement in the hearts of our producers. We should assure the security of the consumer. Our Government is doing that. Let us admit it."

Congressman Abernethy issued a minority report concurring with the views submitted by Congressman Horan. He states: "The whole essence of my objections to the report submitted to me by counsel for our committee is that the report is 'alarmist' in nature. It would, in my opinion, contribute to the difficulties of our producers of foodstuffs in the United States and yet add nothing of assurance to the consuming public." . . .

"I am convinced that the majority report as presently constituted adds nothing in this direction and therefore I cannot be a party to it. I feel very strongly that the report is reactionary and a deterrent to needed progress.

"While parts I and II of the report as submitted to me on June 25, and unchanged in later presentations are subject with one exception, later referred to in my conclusions, to my endorsement, I find part III to be fraught with inequities and inaccuracies. To my mind, it does but little good to discuss, as is done in the beginning of part III, seven chemicals which are by today's legal procedures denied access to interstate commerce. Far better to have mentioned those seven chemicals by name and to have assured the consuming and producing public of the efficiencies of our tax-supported agencies which have succeeded in denying these chemicals the privilege of interstate commerce.

"And, again, in part IV, the report indicates that selenium may be used as an agricultural insecticide. Selenium has been registered by the Department of Agriculture under the Insecticide Act of 1947 for only one crop use and for use on ornamentals and certain green house purposes. It has not been registered for use on any other food crop and its sale for use

on any other food crop would be illegal and the product could be seized under existing law. Selenium is not permitted on apples and the indirect reference to their use thereon is not only unfair—it is destructive.

“It is one thing to raise an alarm; it is another thing to put out the fire.

“Again, in the discussions of the use of chemical emulsifiers used in a wide range of foods, as it appears on part III and again is enlarged upon in part V of the report, it should be borne in mind that the harmful toxicity of emulsifiers has never been proven.

“The burden of testimony would lead one to the conclusion that they are nontoxic and therefore any discussion of them is economic rather than a question of the effect of the health of individuals.”

Comments on The Hearings

The testimony presented at the hearings on chemicals in foods, House Resolution 323, 81st Congress, 2nd session³³, is of varied character, and part of it is difficult to evaluate. Some of the scientific matter introduced by reputable scientists is sound in so far as the facts are concerned. Such men had scientific data obtained in well planned experiments. However, much of the evidence from other sources is difficult to evaluate as it did not rest on controlled experimental work. Some of the material presented was not factual but represented opinion or point of view. Much more effort should have been made to educate the public concerning the excellent work the Food and Drug Administration, the Department of Agriculture, State Experiment Stations, and State land-grant colleges are doing in protecting the consumer, as well as promoting larger food supplies by the proper use of pesticides. Functional additives also have enhanced certain foods and made it possible to make foods more acceptable to the consumer.

There is a vast program of research carried on by the various government agencies and by industry designed to improve food products, prevent production losses, improve quality and acceptability with a minimum of hazard to the consumer. The interest of the consumer is a paramount consideration in every industrial organization. The report of the Delaney committee failed as an educational effort. It did not have the weight a clearly defined factual report would have carried. Consequently, a large part of this effort was ineffective, and it failed to create a clear picture of what is defective and needs correction in our food laws.

Kleinfeld³⁴ states that the Delaney committee is of the opinion that although rapid strides in the application of science to the production and processing of food offer great possibilities for the welfare of mankind, this progress has been attended by a certain degree of hazard, since some quantity of many of the substances utilized in the production and processing of foods is inevitably ingested by the consumer. The desire is to reduce the

risk to a minimum. As a result of the hearings a number of food additives bills have been introduced into Congress. These bills were supported by various industrial groups.

New Legislation Proposed

Since the Delaney hearings were completed, a number of bills covering chemical additives have been introduced into Congress. A bill covering standards hearings and one concerning residues of pesticides have been passed. However, to date, two years after the report appeared, no chemical additive bill has received the approval of all the various groups involved. This seems to indicate that the work of the Delaney committee was not precise or fully effective. The Delaney committee could not agree on a final report, and Congress was faced with difficulties in getting the precise facts and establishing the needs of industry and the consumer. The problem of developing effective new legislation within the framework of a free enterprise concept of government and consistent with the evolution of our republican institutions is, indeed, difficult and presents many problems.

One of the first bills presented to the 81st Congress, 2nd Session, was the Miller bill³⁵, H.R. 3257. This bill had several features which aimed to control the introduction and use of new chemicals more effectively. It proposed that new chemicals designed for use in foods may be used only after permission has been granted by the Food and Drug Administration, based on the evidence submitted for the safety of the chemicals intended for use in a food product. The bill was designed to control specifically the new chemical additive itself rather than the finished food in which it is used. In view of the many combinations of ingredients that may be involved, this procedure may not protect the consumer.

Many features of this bill were considered unsatisfactory by some manufacturers in the food and chemical industries. Some contended that the present law is adequate to protect the consumer, and that the Food and Drug Administration has ample authority to empower the government to prevent the sale of a product which "bears or contains any poisonous or deleterious substance" which may render it injurious to health. It was also contended that the Miller bill did not provide a definite answer to the question of judging the evidence for safety; nor was the problem of the right of judicial appeal clearly defined.

Oser³⁶ discussed the regulation of chemicals in food and the problems involved in gauging toxicity. Many interesting points of view are developed in this paper.

The Manufacturing Chemists' Association in 1952³⁷, after studying existing legislation and various proposals for new legislation, concluded that existing legislation vests the government with adequate authority over the

use of chemical additives. There is, however, one area where it may be logical to apply a correction; that is, assurance that advance information is supplied by industry to the Food and Drug Administration with respect to proposed new uses of chemical additives. Under this proposal use of chemical additives may be initiated after 90 days notice, provided the Food and Drug Administration has not taken action on the ground that the substance is toxic and deleterious to health. The manufacturer assumes responsibility for his product in any case, whether he operates as at present or under authority such as is provided in the Miller bill.

A number of new bills, covering legislation pertaining to foods, were introduced in the 82nd Congress, 1st and 2nd Session, and the 83rd Congress. The Miller bill³⁵ on foods, H.R. 3257, was not offered in the 83rd Congress. One of the bills which has been of great interest to the food industry is the Hale bill, H.R. 6434³⁸. The subject matter of this bill was discussed and supported by Mr. Markel³⁹, prior to its introduction to Congress, and by Dr. Williams and his committee on Food Standards of the Food and Nutrition Board, National Research Council. They approved the bill as a reasonable method of simplifying procedures governing the establishment of food standards. It provides that a mandatory standard may be issued, amended, or repealed without public hearing, provided there is no controversial issue involved. This bill was passed in the 83rd Congress, 2nd Session, and signed by the President.

Another bill, A. L. Miller, H.R. 7125⁴⁰, 83rd Congress, 2nd Session, is of indirect interest to the food processing industry. It amends the Federal Food, Drug, and Cosmetic Act in respect to residues of pesticide chemicals in or on raw agricultural commodities, and defines the term "pesticide." Its object is to speed up the method for regulating, under the Federal Food, Drug, and Cosmetic Act, the amount of residue which may remain on a raw agricultural commodity following the use of a pesticide. Upon application by the manufacturer, the administrator may set tolerances for a pesticide on a raw commodity or reject its use within certain time limits. He may consult an advisory panel, and provisions are made for judicial review. This bill was passed by the 83rd Congress.

The Delaney bill, H.R. 2245⁴¹, 83rd Congress, 1st Session, to regulate chemical additives in foods, defines a chemical additive as "any substance, including products resulting from changes in such substances after use which (1) is intended for use (a) as a food, or (b) to preserve or alter any food or any characteristic of a food, or (c) as a pesticide or for any other purpose in producing, processing, packing, transporting, wrapping or holding food if such is likely to result in the contamination of the food; and (2) is not generally recognized, among experts qualified by scientific training and experience to evaluate the safety of such substances, as having been adequately tested to show that it is not poisonous or deleterious, or is a

poisonous or deleterious substance which is not generally recognized among such experts as having been adequately tested to show that it is safe for an intended use described in this paragraph.”

The bill also outlines methods for filing a request for issuance of an order approving the use of a chemical additive. The duties of the administrator are also outlined and his procedures defined.

The O'Hara bill, H.R. 9166⁴², 83rd Congress, 2nd Session, proposes amendments to the Federal Food, Drug, and Cosmetic Act to prohibit the use in food of new chemical additives which have not been adequately tested to establish their safety. Section 201 of the Federal Food, Drug, and Cosmetic Act is amended by adding at the end thereof the following new paragraph:

“(s) The term ‘new chemical additive’ means any substance the intended use of which results or is likely to result in its becoming a component of any food, including substances intended to preserve or alter the food or for any other purpose in manufacturing, producing, processing, packing, wrapping, transporting, or holding the food, which is not generally recognized, among experts qualified by scientific training and experience to evaluate the toxicity or other potentiality for harm of such substances, as having been adequately shown through scientific procedures or through prolonged use in food not to be a poisonous or deleterious substance for its intended use. The term does not include pesticide chemicals in or on raw agricultural commodities.”

Section 2. Clause (2) of section 402 (a) of the Federal Food, Drug, and Cosmetic Act is amended to read as follows:

“(2) (A) If it bears or contains any added poisonous or added deleterious substance, except a pesticide chemical in or on a raw agricultural commodity, which is unsafe within the meaning of section 406; or (B) if it is a raw agricultural commodity and it bears or contains a pesticide chemical which is unsafe within the meaning of section 408 (a); or (C) if it is or if it bears or contains any new chemical additive which is unsafe within the meaning of section 409 (a);”

Sec. 3. Chapter IV of the Federal Food, Drug, and Cosmetic Act is amended by adding at the end thereof the following new section:

“New Chemical Additives

“Sec. 409. (a) Unsafe Chemical Additives. Any new chemical additive shall be deemed unsafe for the purposes of the application of clause (2) (C) of section 402 (a) unless a regulation has been issued by the Secretary pursuant to paragraph (c) of this section announcing that the new chemical additive is not a poisonous or deleterious substance for its intended use.

“(b) Application To Show Safety. Any interested person shall have the right to file with the Secretary an application containing scientific data for

the purpose of establishing that a new chemical additive is not a poisonous or deleterious substance for its intended use. The application shall contain data showing—

“(A) the name, chemical identity, and composition of the new chemical additive;

“(B) the proposed use of the new chemical additive together with functional use information;

“(C) a full description of the methods used in, and the facilities and controls used for, the production of the new chemical additive;

“(D) a description of the methods for quantitative determination of the new chemical additive, and its reduction products, in or on food;

“(E) all directions, recommendations, and suggestions proposed for the use of the new chemical additive, including specimens of its proposed labeling;

“(F) full reports of investigations made with respect to the toxicity or other potentiality for harm of the new chemical additive;

“(G) a proposed regulation announcing that the new chemical additive is not a poisonous or deleterious substance for its intended use; and

“(H) reasonable grounds in support of the application. Samples of the new chemical additive and of articles used as components thereof shall be furnished to the Secretary upon request. Notice of the proposed regulation shall be published in general terms by the Secretary within thirty days after filing.

The remainder of the bill covers (c) Action on Application, (d) Reference to Advisory Committee, (e) Objection to Regulations; Public Hearing on Objections; Final Order, (f) Appointment of Advisory Committee, (g) Judicial Review, (i) Amendment and Repeal of Regulations.

Summary of H.R. 9166

The O'Hara bill, H.R. 9166⁴² has replaced the former H.R. 8418⁴³ and is designed to meet some objections to it. The new bill lists four factors which the Food and Drug Administration must consider in determining whether a product containing such a food additive is safe for human consumption:

- (1) Functional value of proposed additive.
- (2) Total probable consumption of the additive in all foods.
- (3) Cumulative effect of such substances in the diet.
- (4) Safety factors in translating laboratory tests to human use.

Temporary Permits to Allow Test Marketing

The Department of Health, Education, and Welfare⁴⁴ has provided procedures for the issuance of temporary permits for interstate shipments of

experimental packs of food varying from the standardized product and varying in the standard of identity³⁵. The Department recognizes that appropriate investigations to provide potential knowledge for advances in food technology may require tests in interstate commerce markets to determine advantages and consumer acceptance. It is the purpose of the Department to permit such tests where they are necessary to the completion or conclusiveness of an otherwise adequate investigation and where the interests of consumer are adequately safeguarded. The Department will refrain from recommending regulatory procedures under the Act on the charge that a food does not conform to an applicable standard, if the person who introduces or causes the introduction of the food into interstate commerce holds an effective permit from the Secretary, providing specifically for those variations in respect to which the food fails to conform to the applicable definition and standard of identity. This procedure should provide a means of freeing research and would permit development of new products.

Factory Inspection

The 83rd Congress passed H.R. 5740⁴⁵, an Act to amend the Federal Food, Drug, and Cosmetic Act, so as to protect the public health and welfare by providing certain authority for factory inspection and for other purposes. This law is indirectly of interest in connection with our discussion of chemicals in foods because it empowers the Food and Drug Administration to report on conditions in food plants whereby a food may have been rendered injurious to health.

Section 704 (a), under "Factory Inspection" states "For purposes of enforcement of this Act, officers or employees duly designated by the Secretary, upon presenting appropriate credentials and a written notice to the owner, operator, or agent in charge, are authorized (1) to enter, at reasonable time, any factory, warehouse, or establishment in which food, drugs, devices, or cosmetics are manufactured, processed, packed, or held, for introduction into interstate commerce or are held after such introduction, or to enter any vehicle being used to transport or hold such food, drugs, devices, or cosmetics in interstate commerce; and (2) to inspect, at reasonable times and within reasonable limits and in a reasonable manner, such factory, warehouse, establishment, or vehicle and all pertinent equipment, finished and unfinished materials, containers, and labeling therein. A separate notice shall be given for each such inspection, but a notice shall not be required for each entry made during the period covered by the inspection."

The bill also states that the inspector shall render a report setting forth in writing "any conditions or practices observed by him which, in his judgment, indicate that any food, drug, device, or cosmetic in such estab-

ishment (1) consists in whole or in part of any filthy, putrid, or decomposed substance, or (2) has been prepared, packed, or held under insanitary conditions whereby it may have become contaminated with filth, or whereby it may have been rendered injurious to health."

Provisions for sampling are also included in the bill.

Comments and Analyses of Present and Proposed Legislation Covering Additives

The proposed legislation on chemical additives shows a divergence of views. The Food and Drug Administration and the food manufacturers have not reached agreement as to the fundamental principles on which a law is to be based, and on the operating procedures. Undoubtedly influenced by the divergence of views it encountered, Congress hesitated to take action. In the case of the Hale bill, H.R. 6434³⁸, and the Miller bill, H.R. 7125⁴⁰, there was very little opposition, and the Food and Drug Administration and the industries involved were in essential agreement. Congress thus felt assured and passed these measures.

The O'Hara bill, H.R. 9166⁴², has been criticized. The basic fallacy inherent in Sec. 402 (a) (2) and Sec. 406 (a) lies in the fact that these sections are based on the view that all substances may, without reference to quantity, method of use, et cetera, be classified as either toxic or deleterious substances on one hand, or nontoxic or nondeleterious substances on the other.

A substance has toxic properties only in relation to the quantity that is present in the food and the amounts that might be consumed in a given time. Oser⁴⁶ states "There is no foundation in toxicology for regarding all substances either poisonous or deleterious on the one hand, or safe and harmless on the other. . . . Toxicity depends on species, age, weight, sex, dosage, route of administration, physiological or pathological state, and manifold other factors comprising experimental conditions. Translation of toxicity data into terms of real or potential effect under any given set of circumstances, as for example, the determination of hazard to any particular segment of the population or to the public health generally, involves considerations that go far beyond toxicity effects in laboratory animals".

Oser⁴⁶ also states "There is no zero degree of toxicity, of poisonousness, of deleteriousness, or indeed, of hazards."

Section 406 (a) establishes procedures, according to Snyder, for determining tolerances for food ingredients. However, the food manufacturer to obtain approval of an ingredient must under that section (1) allege that the substance proposed to be used is poisonous or deleterious, and (2) he must be prepared to prove that the ingredient is required or its use cannot

be avoided in the production of the food. This is a difficult burden, and except in the case of spray residues, would be practically impossible in many instances. Snyder⁴⁷ defines his position by quoting Oser⁴⁶.

Some manufacturers would like to have a procedure which will permit them to use a substance which has been adequately pretested, but without the burden of showing that without the substance the food cannot be reproduced. The problem immediately arises—what is adequate pretesting?

Snyder⁴⁷ proposed elimination of the language presently appearing in Section 406 (a). Section 406 would then consist solely of the provisions presently found in Sec. 406 (b) relating to harmless coal-tar colors. He would amend Sec. 402 (a) (2) which at present provides that a food is adulterated "if it bears or contains any added poisonous or added deleterious substance except a pesticide chemical in or on a raw agricultural commodity which is unsafe within the meaning of Sec. 406," to read as follows: "If it is or if it bears or contains any new chemical additive which is unsafe within the meaning of Sec. 409 (a), or if it is a raw agricultural commodity and it bears or contains a pesticide chemical which is unsafe within the meaning of Sec. 408 (a)." Sections 409 (a), 409 (b) (G), 409 (c), and 409 (d) should be changed to read "the new chemical additive is not such a poisonous or deleterious substance when used in the quantities and manner intended as may render the food in or on which it is intended to be used, injurious to health."

The method of filing application for new additives is carefully defined in H.R. 9166⁴². The applicant must show the scientific data, analysis of the product, methods for control, all directions, recommendations, and suggestions proposed for use in the new chemical, full reports of investigations made with respect to the toxicity or other potentiality for harm. Provision for an advisory committee and its appointees is included. There are provisions to enable any person adversely affected to object to the regulation and to obtain a public hearing. Judicial review is also provided. Procedures are developed for amendment and repeal of regulation.

This bill has the backing of several food groups. The Food and Drug Administration is said to approve it except for one provision that would require a new additive to be judged on the basis of its intended use. The Food and Drug Administration thinks this would end in approving chemicals for a single food use without considering total intake from all sources.

The Miller bill, H.R. 4901⁴⁸, has drawn opposition from both food and chemical manufacturers. It will be rewritten and may be introduced later.

Bing⁴⁹ discusses some of the problems involved in the use of chemicals. He has outlined his views as they apply to the food industry. He favors adequate pretesting and permission control.

Bing⁵⁰ states that the maintenance of the integrity of our foods involves a re-examination of some of the ingredients commonly used in foods for years. New products from the fermentation industries should also be adequately tested.

There is need, he states, for a major revision of the Federal Food, Drug, and Cosmetic Act based on required pretesting and approval of food additives regardless of their origin. The authority to administer the new law should be assigned to one agency with no reviewing body except the courts.

St. John⁵¹ gives an excellent outline of some of the problems faced by the food and agricultural industries in the use of chemicals, especially pesticides. He defines incidental and intentional additives, and discusses some of the hazards involved as well as the need for chemicals in these industries.

Oser⁵² in a philosophical paper has given serious consideration to some of the problems involved in connection with the functions of the scientist and the lawyer in the operation of the Food, Drug, and Cosmetic Act of 1938, and the matter of amending and interpreting it. In a recent paper⁵² he has analyzed some of the factors involved in the proposed amendments to the Food, Drug, and Cosmetic Law. He points out that this is a criminal law and that all segments of the food industry should be familiar with its provisions. The portions of the 1938 Food, Drug, and Cosmetic Act which regulate chemical additives come under the head of adulteration and misbranding. A food is adulterated if it bears or contains any poisonous or deleterious substance which may render it injurious to health. The Act also states "any poisonous or deleterious substance added to any food except where such substances are required in the production thereof or cannot be avoided by good manufacturing practice shall be deemed unsafe." Thus these substances are considered as adulterants. The Secretary of Health, Education, and Welfare is empowered to establish tolerance limits in the case of spray residues if he finds it necessary in order to protect the public health. It should be noted that the basis for fixing tolerance levels is not simply safety in itself but also practical need, bearing in mind that poisonous or deleterious substances are involved.

Thus there was one method of preventing or controlling the presence of chemicals of the pesticide type. The new law, H.R. 7125⁴⁰, recently passed, concerns tolerances in respect to residues of pesticide chemicals in or on raw agricultural commodities. The word "pesticide" is defined in the Act. The term "raw agricultural commodity" is defined as "any food in its raw or natural state including all fruits that are washed, colored, or otherwise treated in their unpeeled natural form prior to marketing⁴³."

An important amendment is included in H.R. 7125⁴⁰, Sec. 2, Clause (2) of Sec. 402 (a) of the Food, Drug, and Cosmetic Act which reads as follows:

“(2) if it bears or contains any added poisonous or added deleterious substance, except a pesticide chemical in or on a raw agricultural commodity, which is unsafe within the meaning of Sec. 406, or if it is a raw agricultural commodity and it bears or contains a pesticide chemical which is unsafe within the meaning of Sec. 408 (a) Any poisonous or deleterious pesticide chemical or any pesticide chemical which is not generally recognized, among experts qualified by scientific training and experience to evaluate the safety of pesticide chemicals, as safe for use, added to a raw agricultural commodity, shall be deemed unsafe for the purposes of the application of Clause (2) of Sec. 402 (a) unless a tolerance for such pesticide chemical has been prescribed by the Secretary of Health, Education, and Welfare under this section and the quantity of such pesticide chemical in or on a raw agricultural commodity is within the limits of tolerance so prescribed; or (2) with respect to use in or on such raw agricultural commodity the pesticide chemical has been exempted from the requirements for a tolerance by the Secretary under this Section.”

The Secretary is given authority to promulgate regulations exempting any pesticide chemical from the necessity of a tolerance with respect to use in or on any raw agricultural commodities when such a tolerance is not necessary to protect the public health. While a tolerance or exemption from tolerance is in effect for a pesticide chemical with respect to any raw agricultural commodity, such raw agricultural commodity shall not, by reason of bearing or containing any added amount of such pesticide chemical, be considered to be adulterated within the meaning of Clause (1) section 402 (a).

The manner in which an application is submitted for the registration of an economic poison under the Federal Insecticide, Fungicide, and Rodenticide Act with the Secretary of Health, Education, and Welfare is prescribed. The applicant must submit reasonable grounds in support of the petition. Notice of the filing of such petition shall be published in general terms by the Secretary within 30 days after filing. Such notice shall include the analytical methods available for the determination of the residue of the pesticide chemical for which a tolerance or exemption is proposed. “Within 90 days after a certification of usefulness by the Secretary of Agriculture under subsection (1) with respect to the pesticide chemical named in the petition, the Secretary of Health, Education, and Welfare shall, after giving due consideration to the data submitted in the petition or otherwise before him by order make public a regulation (a) establishing a tolerance for the pesticide chemical named in the petition for the purpose for which it is so certified as useful, or (b) exempting the pesticide chemical from the necessity of a tolerance for such purpose.”

The petitioner within such 90 day period may request that the petition

be referred to an advisory committee. "The Secretary at any time upon his own initiative or upon the request of any interested person may propose the issuance of a regulation establishing a tolerance for a pesticide chemical or exempting it from the necessity of a tolerance. Thirty days after publication of such a proposal the Secretary may by order publish a regulation based upon the proposal which shall become effective upon publication, unless within such 30 days a person who has registered or who has submitted an application for the registration of an economic poison under the Federal Insecticide, Fungicide, and Rodenticide Act containing the pesticide named in the proposal request that the proposal be referred to an advisory committee." Upon such request the Secretary shall submit the proposal and other relevant data before him to an advisory committee. All data submitted to the Secretary or to an advisory committee in support of a petition under this section shall be considered confidential by the Secretary and advisory committee until publication of a regulation.

"In a case of actual controversy as to the validity of any order under subsection d (5) (e) or (1) any person who will be adversely affected by such order may obtain judicial review by filing in the U. S. Court of Appeals for the circuit wherein such person resides or has his principal place of business or in the U. S. Court of Appeals, District of Columbia, within 60 days after the entry of such order, a petition praying that the order be set aside in whole or in part."

The sponsors of the food additive legislation offered in Congress follow, in general, many of the recommendations made by the Food and Drug Administration. A number of industrial groups have indicated that they support the principles enumerated in the O'Hara bill, H.R. 9166⁴². However, a large segment of the food industry has not publicly accepted the fundamental principles underlying this bill. It is an extension of authority which the food industry and its suppliers have not heretofore had occasion to experience.

These issues relate to the responsibility which the manufacturer of food must assume in introducing a new additive to a food whether standardized or not standardized. He must assume the burden of proving the safety of the product to the satisfaction of the Food and Drug Administration. In standardizing foods the Administrator has an opportunity to control or influence the destiny of the products placed on the market. At present unstandardized foods move into interstate commerce and if the Administrator has evidence that such foods contain harmful or deleterious products, he has authority to seize them and present evidence in court as to their harmfulness. The burden of proof is on the Administrator. Shall the petitioner now assume the responsibility of proving safety to the satisfaction of the Administrator, or of harmlessness when the product is

seized and action is taken by the Court? Will the Administrator exert a profound control over the future course of development of the food industry? Particularly, will the findings of fact by the Administrator be subject to judicial review?

Manufacturers of foods have always accepted as a moral responsibility the control of the safety of their products. They have felt that the initiative should remain in their hands. When placing a new product on the market, they have been keenly aware of the problems involved and their obligations to the public. They have cooperated with the Food and Drug Administration. Shall they abandon the traditional methods and permit the Food and Drug Administration to assume the control in respect to marketing a new product? Will the food manufacturer willingly assume the positive burden of proof in every case when questions of safety arise? Will he give up the initiative? Will the effect of standardization of foods and the difficulties of proving harmlessness to the satisfaction of the Food and Drug Administration, and getting prior approval before marketing a new food product, tend to inhibit research in the food industry?

Hand⁵⁴ states that there are 700 chemicals used in foods today, and 276 have not been adequately proved safe. However, we should not be too greatly concerned about this because many of them appear in extremely small amounts; 70 products represent 90 per cent of our food and in toto contain far less than 700 chemicals. He states that specific toxicity measurements are badly needed. One major weakness of the Federal law is that it provides no definition of what is meant by poisonous and deleterious substances. He believes no change is needed in the present food law for public protection.

Dunn^{56, 57, 58} in discussing food legislation states that there is a growing trend for the Food and Drug Administration to transform the 1938 Act into a government control. Since its inception in 1906, the Act has been designed to express the legislative philosophy of free institutions in their applications to private industry. "It is the philosophy of objectively regulating the conduct of such industry as required by the public interest, to prevent what is injuriously wrong and to command what is beneficially right; whereby its members are otherwise normally left free to achieve the economic success won in a competitive order by their individual business efficiency and public service. An exception to this philosophy, for the substitution of a government permissive control over private industry, is only justified to the extent it is unavoidably essential to assure the public safety. This exception has measurably entered the food and drug law where it is necessary to safeguard the public health. For example, we find it in the advance government inspection laws, relating to milk and meat; in the advance government license laws pertaining to biologic and narcotic

drugs; and in the advance government registration laws applying to pharmacists.

"But we are here mainly interested in the fact that this exception has importantly penetrated the major Federal Food, Drug, and Cosmetic Act of 1938, and that the trend is for its progressive increase there. . . . This conversion of the 1938 Act into a government permission control over new drugs inevitably led to a Food and Drug Administration recommendation of an analogous control over new chemical additives in food and cosmetics."

The O'Hara bill, H.R. 9166⁴², gives the Food and Drug Administration permissive control over chemical "additives in food." According to Snyder⁴⁷ "It outlaws all affected chemical additives and allows their use only on the basis of an Administration permission, granted according to prescribed conditions and subject to the sanctioned court review." This amendment, designed to prevent the use in food of new chemical additives which have not been adequately tested to establish their safety, does not directly require adequate safety pretesting; indirectly it requires pretesting by giving government permission control.

Bartenstein⁷⁷ pointed out that the legislation proposed in the Miller bill, H.R. 3257³⁵, does not permit the court to disturb any result reached by the Administrator if there is any real evidence whatsoever to support his conclusions. Unless the Administrator has acted arbitrarily, his decision becomes final. Except for being subject to review by the Supreme Court of the U. S., the judgment and decree of the Court of Appeals is final.

He⁷⁷ also pointed out that various alternatives are being considered to avoid giving a Federal agency final and unshared responsibility for the scientific decisions and judgments involved. Any law that affects essentially a scientific field is of importance to scientists. There is need for careful, objective study to determine facts on which to base changes in statutes.

Bartenstein⁵³ states that there is a "middle-of-the-road" approach between the view of those who believe the Food and Drug Administration should be finally "permitted to say 'yes' or 'no' to the use of an ingredient before it is put to use, based on its views of adequacy of testing . . ." and the view of those who hold that every new ingredient proposed for use in foods should be adequately pretested for safety before use; that no man should be his own referee on the issues of safety testing, but that "he continue to bear full responsibility for his own compliance with law, and that the refereeing be by traditional policing and court actions. There seems to be general agreement that all testing data on a substance should be supplied to the government ahead of its use in foods."

He suggests four changes to strengthen the present Act:

"(1) Add a new provision to the Federal Food, Drug, and Cosmetic Act that no new ingredient intended for food use should be shipped in in-

terstate commerce or used in foods unless the shipper or user submits to FDA his full data on safety.

“(2) Add a provision that the Administration have a reasonable time in which to review this data.

“(3) Amend the law to provide that it is a violation to ship an ingredient (or a food containing it) which is unsafe in the manner used or intended to be used, or which has been inadequately tested for safety for food use.

“(4) To resolve initial differences between FDA and the supplier or user of the ingredient, add a provision for informal conferences and, possibly, for advisory scientific bodies to be available to either government or industry.”

General Comments on the Use of Additives

The development of biological and chemical science has increased the complexity of toxicological and pharmaceutical techniques. Methods should not be too complicated or require an extended period of time, provided safety or lack of hazard can be determined by more concise procedures. There is always the danger that the methods of appraisal will become so complex that progress will be hampered¹². The philosophy on which the Food and Drug Administration evaluates the safety of a chemical used in food products revolves around the definition of a poisonous or toxic substance; namely, Section 402 states “A food shall be deemed to be adulterated—(a) (1) If it bears or contains any poisonous or deleterious substance which may render it injurious to health; but in case the substance is not an added substance such food shall not be considered adulterated under this clause if the quantity of such substance in such food does not ordinarily render it injurious to health . . .” Oser⁴⁶ has given an excellent discussion of this problem.

Perhaps the definition of what is a poisonous or harmful substance as stated in Section 402 should be rewritten, or a broader interpretation should be given. Toxicologists and pharmacologists have suggested and used various procedures in determining hazards in connection with chemicals of varying degree of toxicity. The degree of hazard permissible is also a matter which has not been well defined, and agreement has not been reached as to the levels at which a substance may be potentially toxic. On what basis shall additives be employed, that is, on dry weight, calories, or functional needs? The history of the use of chemicals indicates quite definitely that the idea of the development of all possible information is not possible or necessary before the particular chemical compound can be utilized effectively in industry.

Lehman⁵⁹ states that it was formerly believed that body fat was an inert reservoir. Recent experimental evidence points toward the view that the

presence of a chemical foreign to the body should be viewed as a potential danger. Of 75 samples of human fat analyzed, DDT or a metabolite was found in all but 15 samples. The average was around 5 ppm. Some samples ran as high as 20 ppm. Rats fed 5 to 10 ppm DDT in the diet stored DDT in the fatty tissues at 6 to 14 times this intake. Chlordane fed to the rat at $2\frac{1}{2}$ ppm was found at a level of about 26 times the intake in the fat. Methoxychlor is not stored under normal conditions, and levels must reach at least 200 ppm or more before injurious effects can be noted. He concludes that in taking a conservative attitude toward the indiscriminate use of insecticides there is no necessity to restrict their use below limits where they would serve a useful purpose. A relaxation of controls is not justified on the basis of present scientific knowledge.

According to Frazer⁶⁰ the hazards should be evaluated at the levels to be used, the levels of acute toxicity and chronic toxicity, and all possible levels that might be encountered during processing. From practical considerations there is a limitation in determining all the manifestations, metabolical and physiological, which the chemical compound may exert. Procedures that are not too cumbersome and economically too burdensome should be found. They must be designed so that the toxic levels can be evaluated with a high degree of accuracy. The potentialities for harm, which a product presenting hazards may possess when distributed at varying levels in a number of different food products, should not be underestimated. Frazer⁹⁴ also discusses provisions for adequate safeguards for the use of additives. It is desirable that human studies be carried out whenever possible.

To be of value to the research investigator, the toxicological tests should be contemporaneous with the development studies of the compound. If the substance meets the rigorous requirements of the industrial toxicological laboratory, the investigator may proceed with his development work.

Adams⁶¹ states, and the Medical Research Council of Great Britain agrees, that possible dangers from novel substances in food, food processing agents, and food contaminants should be kept under continuous observation, but advises that no new measures are at present required to control dangers from medicines and other consumer goods.

The following statement⁶² by the President of the Advisory Council on Scientific Policy, Great Britain, is of interest: "The risk to life and health due to the presence of toxic substances in consumer goods is probably small, but the rapid growth of the chemical industry, and needs of the food processing industries for substitutes to replace scarce materials or for chemical substances which have a claim to use on their own merits as improvers of the appearance, palatability or texture of manufactured foods, are accelerating the pace at which new chemical substances are

being introduced into consumer products, and the machinery which exists for testing the possible harmful effects of these substances is inadequate."

Stare⁶³ states that we should not permit fads to determine our eating habits. "I do not condemn whole wheat, I just say there is no reason it is better than enriched products from a practical viewpoint in nutrition."

St. John⁵¹ analyzes the factors that must be considered in order to use chemicals safely. He tries to answer the questions, "Why is it not possible in this modern world to have foods entirely free from added 'chemicals.' What are the advantages, nutritional and technological, resulting from the use of 'chemicals'?"

McHenry⁶⁴ points out that the deficiency disease, rickets, can occur in children up to age 14. It is certain that rickets can be prevented if children have sufficient vitamin D. In a recent study in Toronto he found that three-fourths of the children were not given vitamin D. He infers that the addition of vitamin D to some product, such as milk, which is widely used, is desirable to provide effective control. Treatment of a natural product with a chemical additive would be in the public interest.

Sebrell⁶⁵ states it is important that we safeguard the broad nutrition advances made in the last decade. We cannot count on their permanence. It is desirable to continue our efforts to improve foods and food habits. Many people may not be adequately fed in spite of the progress we have made in improving our foods. We do not have diagnostic methods for determining borderline deficiencies. Foods, therefore, should be adequate for it is believed that diet plays an important role in the prevention and treatment of chronic diseases, not known to result from dietary deficiencies. Sebrell⁶⁶ concludes "In the increasing number of health problems facing us in an aging population, chemistry will play an important role."

Hegsted and Stare⁶⁷ have discussed the world food restrictions. The nutritive requirements of man are no more complicated than that of the chick or monkey. Much work remains to be done. In certain areas of the world, food is never sufficient and cereals contribute most of the calories and practically all of the protein. It is in these areas that kwashiorkor, a disease of infants and children, exists. Milk will control the disease, but peasant agriculture will not change. The addition of amino acids to a corn diet or rice diet will correct the condition. It will be simpler to do this by chemical means than by education to develop a new agriculture. "The farmer and the chemist together can do a better job of solving global nutrition than either one alone," Stare states.

Krehl and Cowgill⁶⁸ suggest that in view of the importance of chemicals in nutrition, in modern food processing and manufacturing, a National Foundation of Food technology be established. It should be supported by the food and chemical industry.

Hand⁵⁴ believes the present Federal legislation is sufficient to give full protection and safety to the consumer; self regulation by industry is desirable. He suggests that three steps be taken: (a) The number and scope of toxicity tests should be increased. (b) Full disclosure should be made of the chemical additives used in foods and the results of the tests conducted to prove their safety. (c) A list of intentional additives suitable for use in foods should be drawn up and made available to all food companies.

The necessity for reexamining the safety of some natural food products long in use is pointed out by Sevringhaus⁶⁹. Coumarin, which is a naturally-occurring flavoring material can also be made synthetically. The Food and Drug Administration withdrew this flavoring agent from sale for use in food. He quotes Frazer: "Synthetic chemicals are no more likely to be toxic than natural substances. . . . The direct or indirect effects of any food additives on biological systems may be adequately assessed by the application of appropriate pharmaceutical methods, based on adequate knowledge of biochemical properties of the substances under test and a full appreciation of the nutritional implications. . . . The importance of relating pharmacological effects to dosage cannot be over emphasized. Dosage levels of all chemical substances can be roughly classified from a pharmacological point of view, as ineffective, effective, toxic, and lethal. With most common drugs the general ratio of ineffective, effective, toxic, and lethal dosage in man is not greater than 1:10:100:1000."

Parsons⁸ gives the permissible levels of a number of chemicals found in or added to foods, such as nickel, copper, and lead. Analyses of a number of foods giving the normal content of copper, iron, zinc, arsenic, fluorine, manganese, selenium, and aluminum are also given. He suggests that a system of legal tolerances is desirable. However, if limits are set, the manufacturer should not slacken his efforts to improve the purity of his product.

Williams⁷⁰ stated that the question of safety of new chemical additives proposed for use in foods should be removed from the scope of hearings for standard making purposes. These questions should be settled by scientific inquiry in preference to quasi court procedures. The procedures have been time consuming and wasteful in that the scientific and legal personnel of many corporations have been held at Washington for months to attend hearings. He proposed that the scope of test marketing permits be extended to include "(a) new foods which deviate from standards, otherwise the introduction of a new ingredient will be impeded, (b) foods which purport to be a standardized article by resemblance to same, (c) extension of term of permit until a new standard comprising the article can be promulgated." It is also proposed that practical means be found to enable full representation of interested industry at prehearing discussions with the Food and Drug

Administration concerning Food Standards proposals which may be projected.

Peters⁷¹ discussed the effects of legislative controls on research and development. He believes that the whole problem of chemicals in foods and proposed legislation should be considered from the standpoint of public interest and the effect such measure will have on research and manufacturing. "Legislation giving the Food and Drug Administration the power of life and death over new food products will result in loss of industry incentive, will decrease the amount of research, will lower the morale of research personnel and will progressively reduce the rate of progress in the food industry in years to come."

Crawford⁷² gives a clear statement of his views on chemicals in foods. He supported the Miller bill, H.R. 3257³⁵. This address should be read in full. "The Federal Food, Drug, and Cosmetic Law of 1938 defines any food as adulterated (1) if it contains a poisonous or deleterious substance which may render it injurious to health, or (2) if it contains any such substance that is not required in the production of the food or that can be avoided by good manufacturing practice, or (3) where it is not required or cannot be avoided, if it exceeds the tolerance prescribed by the Federal Security Administrator after public hearing." In prescribing a tolerance the law directs the Administrator to take into account the extent which the poisonous and deleterious substance is required or cannot be avoided in the production of such food. Tolerances can be established only when toxicity of the substance is known. Crawford states "The language chosen to prevent the unnecessary addition of poisonous or deleterious substances is worthy of careful study. Traffic in food containing such a substance, in any quantity whatever, is prohibited except where such substance is required in the production thereof or cannot be avoided by good manufacturing practice."

While the meaning of the word "required" has not yet been interpreted by appellate courts, it seems fair to assume that a real or fancied improvement or advantage resulting from an added poison would not be enough, that to satisfy the law the added substance actually must be essential to production.

Newton⁷³ has taken a strong position for government control over foods containing additives and the marketing of foods so treated. He believes legislation similar to that governing the meat industry should be adopted by the entire food industry. As an illustration, he cites the following from section 4 of the Meat Inspection Act (21 U.S.C.A., sec. 74) "and said inspectors shall mark, stamp, tag or label, as 'inspected and passed' all such products found to be sound, healthful, and wholesome, and which contain no dyes, chemicals, preservatives, or ingredients which render

such meat or meat food products unsound, unhealthful, unwholesome, or unfit for human food."

Prior testing and permissive marketing of all foods to which chemicals are added are recommended in his testimony given at the Delaney Committee hearings. He states "The law should be clear on both points so that while it protects the public, it should also be clear in its provision to prevent an arbitrary and unsound ruling from impeding progress."

Newton⁷⁴ calls attention to the fact that the number of chemicals proposed for use in foods has greatly increased in recent years. This makes it impossible for the Food and Drug Administration to protect the public on a practical basis under the present law, in spite of the fact that it has the authority to seize any interstate shipment that contains any poisonous or deleterious substances. In some cases it would require several years to prove that an additive was harmful. To correct this situation, he proposes a change in the food law making it necessary for the person marketing a new additive to prove that it is harmless. He quotes the resolutions adopted by eight trade associations defining the responsibilities which should guide the food industry.

McNew⁷⁵ discussed the ways that pesticides are removed from agricultural products—by erosion, oxidation, and other means. He outlined briefly the methods for determining the toxicity of the pesticide before it is introduced into commerce. Efforts are being made to eliminate compounds that are not readily oxidized or otherwise destroyed and accumulate in the soil; also compounds that are highly toxic to humans which may tend to concentrate in certain tissues of the body. Pests can be destroyed or controlled effectively, and materials can be developed which will not persist as harmful, dangerous residues at harvest time. The manufacturers of pesticides have set up a comprehensive system of testing each pesticide as it comes from the laboratory with the object of eliminating hazards to the consumer.

Bradley⁷⁶ during the course of his testimony at the Delaney Committee hearing stated "A revised law should make provision for adequate testing of new chemicals to determine their safety and function before such use of chemicals is permitted in the producing or processing of foods." Functionless materials are often sold to food manufacturers by salesmen who convince the user that they perform a special function.

Sebrell⁵⁵ states that chemistry will play an ever more important role, not only as an independent force, but as a requisite to progress in bacteriology, nutrition, and other fields. Future studies will undoubtedly give us better indices for determining the effect of chemical compounds on the body. Much has been learned by chemical studies, and chemicals have improved our health.

Nelson⁷⁸ pointed out that the Food and Drug Administration has re-

cently undertaken the regulation of low sodium foods. It was apparent that the measurement and labeling of low sodium foods was not as uniform and the labels not too specific for the needs of the consumer who is compelled to regulate the sodium content of his diet. The Food and Drug Administration took a number of steps authorized by existing law. It called a hearing and subsequently tentative regulations were issued. Another step covered the statement of policy as to label declarations of salt in frozen vegetables, such as peas, and lima beans which contain salt taken up from the brine in which the mature material is separated from the immature. The Food and Drug Administration also cooperated in a general study of low sodium diets which is proving helpful in advising manufacturers.

Oser⁷⁹ discussed the principles involved in the legislation proposed to control chemicals in foods. The Miller bill, H.R. 3257³⁵, provides that new chemicals in foods may be used only after the safety of their intended use, according to procedures sanctioned by the Food and Drug Administration has been established. This places the burden of proof on the manufacturer. The fact that the Food and Drug Administration approved the use of the chemical in foods would not alter the responsibility of the manufacturer if any toxic manifestations appeared. The decisions as to the use of an additive in a food or its exclusion are made by the Administrator of the Food and Drug Administration. In the event of appeal the Administrator's finding of fact if based on substantial evidence shall be conclusive and binding on the circuit court. The fact that judicial review is not provided in cases where the criterion of safety is the subject of conflicting views has been criticized.

Oser⁸⁰ also states that chemicals are permitted in foods under the 1938 Food, Drug, and Cosmetic Act. The provisions that govern standards specifically state that ingredients be named, and as in bread, the limits for each chemical are given.

In the case of confectionery, Sec. 402 (d) permits the use of a "harmless resinous glaze" and "harmless nonnutritive masticatory substance" in addition to coloring and flavor. Sec. 406 (a) limits poisonous or deleterious substances to those required in production or which cannot be avoided by good manufacturing practice. The Secretary is charged with holding public hearings and promulgating regulations setting tolerance limits to protect the public health. The recent bill, H.R. 7125⁴⁰, passed by Congress excludes pesticides, which were formerly included in this section, from this category. The government must assume the burden of proof in case of enforcement of Sec. 406 (a). Nitrogen trichloride was discontinued by the manufacturers although the evidence against its use was not definite as to its harmfulness for man.

Coumarin, a flavoring ingredient, was withdrawn from sale and use

voluntarily by individual users, and here, also, there was no case of serious human illness, but there was evidence from laboratory experiments on animals that coumarin is toxic. The government did not proceed under Sec. 406 (a) to seize products containing coumarin. Stocks were allowed to be sold.

According to Oser⁸⁰, there are a number of problems arising from the decision to withdraw coumarin for it is present in a number of products, such as the tonka bean, and the usual procedure is to extract coumarin by means of alcohol. The extract is now excluded. Will coumarin obtained by other means be prohibited?

A short public hearing was held for the purpose of removing coumarin from the list of optional flavoring ingredients in the definitions and standards of identity of cocoa and chocolate products. The final order declared that this flavoring agent by reason of its toxic properties is not a suitable optional ingredient of this class of products and deleted it from the standards on May 5, 1954. The Food and Drug Administration also announced in a statement of policy, "Food containing coumarin added as such, or as a constituent of tonka beans or tonka extract will be regarded as adulterated, under the provisions of the law." The Food, Drug, and Cosmetic Act of 1938 defined food as adulterated if it contains any added poisonous or deleterious substance not required in production, etc. Sec. 402 (a) and the Food and Drug Administration will undoubtedly proceed on the assumption that it can prove the poisonous nature of coumarin.

Colors of the certified and permissible coal-tar type are being investigated. Orange No. 1-2 and Red No. 32, also yellow No. 3 and 4 have been suspected of inducing harmful effects when fed to humans. The question arises, are the levels fed and the manner of use in foods to be considered in determining the poisonous or deleterious nature of a substance. Is a substance that exerts an effect when fed at high levels, that is mild but not harmless, to be classified in the same category as one that exerts a deadly effect at low levels?

Artificial sweeteners are also being investigated as to their safety when included in the daily diet. The Food and Nutrition Board of the National Research Council has been requested by the Food and Drug Administration to consider this problem. The Food and Nutrition Board has appointed a committee to study the available literature on the possible toxicity of saccharin and sucaryl and the thickening agents used with them.

Proposed legislation placing restrictions on the use of additives in foods, according to Oser⁸¹, has made one aware of the need for an experimental basis in order to present sound toxicological evidence. The burden of proving harmlessness of a chemical is placed on the manufacturer. There are great difficulties in devising good definitions and standards for safety

and this matter imposes new responsibilities on the Food and Drug Administration. The safety or harmlessness of a food additive is not an absolute concept, but depends on its toxicity, the levels fed, and length of feeding. Proof of complete harmlessness is not realistic or always possible. The methods of testing are often too arbitrary and unyielding.

Oser⁸² discusses many of the important questions concerning present and proposed legislation on chemicals in foods and the control which a standard of identity gives the administrator over such items, as misbranding, as it affects standardized products. The Food Law can be invoked to prevent the presence of accidental or incidental chemical additives in foods.

The Miller bill, H.R. 4901⁴⁸, and the Delaney bill, H.R. 2245⁴¹, adopt the Food Protection Committee's concept of chemical additive as any substance used (in whole or in part) as food, or in processing, packaging, transporting, wrapping, or holding food. The definition states further that an additive is a substance "which is not generally recognized, among experts qualified by scientific training and experience to evaluate the toxicity (H.R. 4901⁴⁸) of such substances, as having been adequately tested so as to show that it is safe for the use for which it is intended."

Will this definition lead to the view that the administrator, or his experts, would be the experts qualified to make such an evaluation? Can an expert employed by a manufacturer assume the responsibility of advising a manufacturer that a chemical additive has been adequately tested? The Miller bill, H.R. 4901⁴⁸, directs its regulatory procedure toward the chemical additive and not directly to the food in which it may be present. The chemical manufacturer would be called upon to assume the major responsibility for filing. This implies that the manufacturer is conversant with all the varied uses of his product.

In connection with the proposed legislation, H.R. 4901⁴⁸ and H.R. 2245⁴¹ a controversy has arisen relating to the position of the petitioner. Is it necessary for him to assume the burden of proving safety, or will the government accept the burden of proving harmlessness when the question arises in the courts? To what extent will the decisions of the administrator and particularly his "findings of fact" be subject to judicial review? The findings or recommendations of the proposed advisory committee are not binding upon the administrator, and may be set aside when he makes public a regulation approving or disapproving an application. If the findings are supported by substantial evidence, they are conclusive. The Delaney bill, H.R. 2245⁴¹, makes provision for judicial review.

Some of the problems which confront the toxicologist concerned with food additives are ably discussed by Oser⁸³. How is one to interpret the incidence of renal calculi, mild hepatitis, glandular changes, or blood dyscrasias in so-called normal or control animals even when the incidence

of such findings is statistically less in the control groups than in the test groups? "The suspicion may be raised of a causal connection to the substance under investigation."

Other problems that confront the toxicologist are the type of basal ration, the food consumption patterns of the economically depressed, of diabetics, of hypertensives, of various national groups, of the aged, of dietary faddists, et cetera.

The situation occasioned by the expression "poisonous or deleterious substances" involves a very fundamental problem. When the term is interpreted from the standpoint of possible injury to public health, the test levels of substances under investigation can be arrived at from consideration of the amounts intended to be used, giving due consideration to factors of safety. However, when interpreted in the absolute sense, without relation to conditions of use, the problem becomes very difficult, and the solution may become an arbitrary one.

The toxicologist must also assume major responsibility, based on his experimental work, concerning the potential hazard, if any, in the use of a new chemical additive. He must translate his findings to apply to humans. He is faced with the problem of balancing the risk, if any, with the potential benefits to the health of society.

While most manufacturers are cognizant of their obligation to establish the safety of new or untried chemical additives, the possibility exists, according to Oser⁸⁴, that the public may be subjected to "possible subtle damage" in cases where a man is ignorant or unscrupulous. Existing legislation provides the means whereby the Food and Drug Administration can check the sale in interstate commerce of a food which "bears or contains any poisonous or added deleterious substance" which may be unsafe. If such a substance is necessary and unavoidable even in good manufacturing practice, the Food and Drug Administration is charged with the responsibility of establishing this fact and is empowered to limit the quantity used to levels where no hazard is involved.

Our present laws provide protection. However, in the case of the introduction of new chemicals, the burden of determining whether a substance is in fact poisonous or deleterious becomes the responsibility of the enforcement agency, and during the time that the agency is investigating the safety of the additive, the consumer is exposed to a hazard, provided the substance is toxic in the amounts used in the food.

The hearings for food standards have provided a forum for the consideration of evidence concerning the safety of new chemicals. However, this procedure has been expensive and laborious and has not worked efficiently. Furthermore, it covers only standardized foods.

SeEVERS⁸⁵ takes exception to the statement made by Dunbar, former

Commissioner of the Food and Drug Administration, before the Delaney House Select Committee to investigate the use of chemicals in food products. He questions the meaning of the terms "poisonous" and "toxicity" as used at present. These terms have been misused and abused. The a priori determination of calculated risk is an exceedingly complicated problem, and in many instances must involve the considered judgment of a large number of fully competent specialists representing a variety of fields including areas not specifically biological. This is true where a prolonged exposure of an entire population is concerned. How is a pharmacologist able to prove that a chemical proposed for use may not under some conditions and over a period of years prove carcinogenic? New chemicals do not differ in any respect except possibly in potency from chemicals formerly in use. Every known chemical is capable of producing a toxic action on man if the exposure is properly made and extensive. The fact that we have created the mechanism for determining toxicity in animals and we are able to determine toxicity in man with a minimum of risk does not mean that we have developed a mechanism for determining justification for use. The matter of becoming an expert in court, and publishing in the field, when the training and experience do not justify such actions, is considered. A satisfactory solution to the problems might be gained by the use of an ad hoc committee complemented by qualified persons of wide experience and judgment in the areas under consideration.

Darby⁸⁶ expresses the point of view of the medical man in respect to nutrition. He uses the definition of Graham Lusk in defining foods as a palatable mixture of foodstuffs. Foodstuffs, in turn, are the materials capable of being added to the body substance or which prevent or reduce the wasting of a necessary constituent of the organism. Additives, intentional or incidental, may be totally usable as foodstuffs, partly usable, or may have no nutritive value whatsoever. Some may possess inherent toxicological properties; certain additives may be inert; others may be used to replace nutrients commonly associated with foods. The nutritionist has a just interest in and a responsibility concerning all these possible functions of an additive.

The considerations in relation to non-nutritive additions in food are different from the considerations which determine whether or not a particular therapeutic agent will be permitted for use in treating sick patients. Foods should be wholesome within the meaning which the Council on Foods and Nutrition of the American Medical Association has provided, that is, "a product which makes a significant contribution to the human dietary requirements and which is clean and free from microorganisms and chemical additives of such quality or in such quantity that may be directly injurious or result in reduced nutritional quality."

Crawford⁸⁷ in replying to the criticism of Seevers gives his approval of the five principles on which the evaluation of toxicity in human beings can be based. He makes it clear that the Food and Drug Administration has not adhered to a policy that there shall be no addition of chemicals to foods. The food standards bear evidence to the contrary. The application of the provisions for the introduction of a new drug should be applied to new chemicals in foods within the framework of the five principles enunciated by Seevers. Seevers criticized the Food and Drug Administration's ban on bread softeners stating they presented no biological hazard. Crawford states that the Food Protection Committee of the National Research Council did not share this view. The Food and Drug Administration is willing to leave the settlement of such issues to the consensus of the nation's scientific experts who are qualified by training and experience in the particular field involved in each case.

Crawford⁸⁸ points out the need of expanding the personnel of the Food and Drug Administration in order to control the use of new substances in foods, to set up new food standards, and to simplify standards procedures. It is necessary to prevent sales to the public of filthy, decomposed foods. Legislation to implement factory inspection is necessary for adequate control. There is need for control of toxic food components in the light of present knowledge. The grain sanitation program must be worked out in a practical manner.

Crawford⁸⁹, reporting on the problem confronting the Food and Drug Administration officials, stated that hearings were held to remove three coal tar colors from the certifiable list because oral toxicity studies had shown them to be capable of serious injury on long time use in small concentrations.

According to Crawford⁹⁰ the consuming public normally regards supplies in grocery stores as pure and safe for consumption, but under stress of national emergency may become skeptical and subject to exploitation. At a time when food is abundant some people have been led under propaganda to believe their families will suffer from malnutrition unless well selected diets are supplemented by prepared "health foods" and dietary specialties. Grave concern is also being expressed by consumers in regard to the safety of the food supply. This concern is augmented by the news reports of the hearings of the Select Committee of the House of Representatives to investigate the use of chemicals in foods. The Food and Drug Administration testified at the hearings that the food and chemical industries as a whole are responsible and conscientious. They have consulted their experts and have abandoned the proposed use of substances whose propriety was questioned. The Administration is recommending new controls to be instituted to curb the fringe of careless, ignorant operators.

Crawford⁹¹ reported that the first pharmacological evidence on the safety of emulsifiers was introduced at the hearings on standards for various salad dressings. In the case of bread the Administrator refused to admit the polyoxides on the ground that the evidence of safety is not convincing, and that their use is likely to be deceptive.

If the safety of chemical additives could be cleared by scientific experts under procedures patterned after those prescribed in the law for new drugs, food standards hearings would involve only the issue of suitability as ingredients of the particular foods under consideration.

Bing⁹² states that a sincere effort has been made and is being made to incorporate a new food additive section in the Federal Food, Drug, and Cosmetic Law. Regulatory control, at the present time, over the safety of new chemicals, or old chemicals put to new uses, applies only to drugs and not to foods and cosmetics. He cites the report of the Committee on Chemicals of the Food and Nutrition Section of the American Public Health Association which recommended the enactment of legislation to require approval, prior to use, of newly proposed additives to foods. The recommendations of the Delaney Committee on chemical additives are also cited.

The Food Protection Committee

The discussions in Congress and among food technologists and food chemists in industry, government, and university laboratories concerning chemicals in foods aroused widespread public interest. A great deal of misinformation by uninformed persons and so-called science writers in the lay press had been disseminated. Confidence in the food industry has always been very great, and the honesty and sound judgment of food and drug officials has never been seriously questioned by responsible persons. However, some of the propaganda indicated that persons interested in advancing their political fortunes or those who wished to secure readers for their publications were using every incident that could be turned against the food industry as an indication that laxity existed, and the consumer's interests were not protected. The general indictment of the food industry, or any segment of it, is unjustified. There is no factual basis for such remarks.

It was considered highly necessary to bring into this situation a group of unbiased persons who were not involved in government control and who had no responsibility to industry. As a result of this need, a group was organized as a committee under the Food and Nutrition Board of the National Research Council. Funds are provided by contributions from industry with some additional support from the National Research Council. This committee, known as the Food Protection Committee, assists

effectively the Food and Drug Administration officials, the public, and industry. It has an industry advisory committee and liaison members from the Food and Drug Administration. To broaden its scope it has organized various subcommittees, namely: food technology, pesticides, toxicology, and chemistry. To further broaden the scope of the Committee, each subcommittee has a panel of advisors selected from universities, industry, and government.

The work of the Committee is purely advisory and educational. In accord with the principles of the National Research Council, it will maintain its objectivity and independence. The Committee proposes to carry out a number of important functions which are as follows:

1. The Committee will assemble scientific information on both incidental and intentional additives, which are used or proposed for use in or on foods, and will summarize and evaluate this information, and make its conclusions available in usable form to those interested.

2. The Committee will advise and assist industry and Federal and State governmental agencies in the integration of research on the utilization of chemicals in food production, processing, and preservation, and promote additional research, by existing agencies, which in the opinion of the Committee appears desirable in the public interest. The Committee itself, however, does not propose to conduct or finance research.

3. The Committee will seek to develop guiding principles and standardized procedures essential to safeguard food.

4. The Committee will encourage and aid in the distribution of accurate scientific information to the general public.

The Committee has made available a number of statements which have had a wide influence. They are informative and, from an educational standpoint, constructive and well organized. They serve as a reference for industry, government, and the consumer.

The following statements have been issued: Statement on the Use of Surface Active Agents in Foods, November 1951; Summary of Progress and Projects, November, 1951; Use of Chemical Additives in Foods, December 1951; Basic Principles Involved in Evaluating Safety in the Use of Chemical Additives in Foods, June 1951; The Safety of Mono and Diglycerides for Uses as Intentional Additives in Foods, December 1952, NRC 251; The Safety of Polyoxyethylene Stearates for Use as Intentional Additives in Foods, August 1953, NRC 280; Annotated Bibliography of Analytical Methods for Pesticides, Section 1, Aldrin and Dieldrin, Benzene Hexachloride, Chlordane and Heptachlor, DDT, December 1952, NRC 241; Safe Use of Chemical Additives in Foods, December 1952.

The Food Protection Committee offers a platform on which industry and government with the assistance of impartial scientists, experts in their fields, can discuss and work out problems of common interest in a demo-

cratic manner. It has exerted a marked influence on the educational program which industry and government have fostered to enlighten the public on the problems which food producers and government agencies have to work out in connection with the production and marketing of foods.

The Food Protection Committee has the confidence of industry and the public. It has received a number of important assignments from the Food and Drug Administration, and the statements issued by the Committee have been of great assistance to industry and to the professional personnel associated with government and educational institutions.

The statement entitled "Basic Considerations in the Development and Marketing of a new Agricultural Pesticide intended for Use in Connection with Food Production", Part III, Safe Use of Chemical Additives in Foods, December 1952, has been greatly needed and should prove to be a useful guide in a difficult and rapidly developing field.

The general objectives for the 1954 program are as follows:

1. To develop better criteria and methods for establishing the safety of food additives.

2. To encourage the kind of research programs necessary to meet the criteria established.

3. To promote cooperation between industry and government with the development and control of chemical additives in foods.

Active problems under consideration at the moment are:

1. The establishment of criteria for the safety of packaging materials.

2. Further study and definition of the phrase "poisonous and deleterious" as legally incorporated in the Food, Drug, and Cosmetic Act.

3. Further study of the basic principles which should be applied to specific additive problems such as the coloring agents.

Conclusion

This chapter was written during 1954 while the 83d Congress was in session. The O'Hara bill, H.R. 9166, and the Delany bill, H.R. 2245, which were proposed at this session were not passed. Consequently, the future course of food legislation remains to be determined. The proposed legislation would transfer extensive authority to the Food and Drug Administration, a policy which may have a profound effect on the future development of the food industry. Government, industry, and the consumer should be fully aware of the significance of the various provisions embodied in the legislative proposals. The potentialities of this philosophy have not been fully explored, but the departure from the concepts underlying our present legislation is clear and precise.

The Food and Drug Administration and the food industry have a splendid record of achievement in maintaining the purity and nutritive value of the food supply of the American people. The Food and Drug Administra-

tion has been alert to changes necessitated by new research and the use of mechanical equipment in industrial processes, new packaging, new devices and materials. The Food and Drug Administration and the food industry have been responsive to the impact of the newer knowledge of nutrition and the recent developments of the chemical, physiological, and bacteriological sciences. They have created and fostered a spirit of constructive cooperation that has permitted unparalleled progress in industry and has made the food supply of the United States superior in every respect to that of any other country. Every effort should be made to continue this great tradition and to sustain progress at an ever accelerating pace consistent with the advances of science and in the spirit of our republican institutions.

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26. THE FEDERAL FOOD, DRUG, AND COSMETIC ACT

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The Federal Food, Drug, and Cosmetic Act was passed in the closing days of the Seventy-fifth Congress and approved by the late Franklin D. Roosevelt on June 25, 1938. Almost exactly five years before, on June 12, 1933, the first bill proposing a complete revision of the existing Food and Drugs Act of 1906 was introduced in the Seventy-third Congress by Senator Royal S. Copeland of New York. Five years of bipartisan consideration produced a measure affording greatly increased protection to consumers and reputable producers.

The urgent need for this legislation was emphasized in President Roosevelt's message to the Congress of March 22, 1935.

"To the Congress of the United States:

"Every enterprise in the United States should be able to adhere to the simple principle of honesty without fear of penalty on that account. Honesty ought to be the best policy not only for one individual, or one enterprise, but for every individual and every enterprise in the Nation. In one field of endeavor there is an obvious means to this end which has been too long neglected: The setting up and careful enforcement of standards of identity and quality for the foods we eat and the drugs we use, together with the strict exclusion from our markets of harmful or adulterated products.

"The honor of the producers in a country ought to be the invariable ingredient of the products produced in it. The various qualities of goods require a kind of discrimination which is not at the command of consumers. They are likely to confuse outward appearance with inward integrity. In such a situation as has grown up through our rising level of living and our multiplication of goods, consumers are prevented from choosing intelligently and producers are handicapped in any attempt to maintain higher standards. Only the scientific and disinterested activity of government can protect this honor of our producers and provide the possibility of discriminating choice to our consumers.

"These principles have long been those on which we have founded public policy. But we have fallen behind in their practical application. No comprehensive attempt

at reform in the regulation of commerce in food and drugs has been made since 1906. I need not point out to you how much has happened since that time in the invention of new things and their general adoption, as well as in the increase of advertising appeals. Because of these changes loopholes have appeared in the old law which have made abuses easy.

"It is time to make practical improvements. A measure is needed which will extend the controls formerly applicable only to labels to advertising also; which will extend protection to the trade in cosmetics; which will provide for a cooperative method of setting standards and for a system of inspection and enforcement to reassure consumers grown hesitant and doubtful; and which will provide for a necessary flexibility in administration as products and conditions change.

"I understand that this subject has been studied and discussed for the last 2 years and that full information is in the possession of the Congress.

"No honest enterpriser need fear that because of the passage of such a measure he will be unfairly treated. He would be asked to do no more than he now holds himself out to do. It would merely make certain that those who are less scrupulous than I know most of our producers to be, cannot force their more honest competitors into dishonorable ways.

"The great majority of those engaged in the trade in food and drugs do not need regulation. They observe the spirit as well as the letter of existing law. Present legislation ought to be directed primarily toward a small minority of evaders and chisellers. At the same time even-handed regulation will not only outlaw the bad practices of the few but will also protect the many from unscrupulous competition. It will, besides, provide a bulwark of consumer confidence throughout the business world.

"It is my hope that such legislation may be enacted at this session of the Congress."

Although two more years passed before Congress enacted the legislation recommended by the President, the law as finally enacted provided most of the controls recommended by him. It included other important provisions, such as authority for the regulation of new drugs. A tragic incident occurring during the two year period clearly established that new drugs must pass tests for safety before they are marketed.

Advertising is in many respects an extension of labeling as the President's message recognized. Congress did not, however, include control of advertising in the Food, Drug, and Cosmetic Act. Instead it provided for more extended advertising control in separate legislation administered by the Federal Trade Commission.

The Committee on Interstate and Foreign Commerce of the House of Representatives filed a report (75th Congress, 3rd Session, Report No. 2139) on April 14, 1938, summarizing the general purposes of the proposed law in these words:

"This Act seeks to set up effective provisions against abuses of consumer welfare growing out of inadequacies in the Food and Drugs Act of June 30, 1906, as amended. That act is popularly known as the Wiley Pure Food Law because that great pioneer in pure food and drug legislation, Dr. Harvey W. Wiley, led the fight for its enactment.

"While the old law has been of incalculable value to American consumers, it contains serious loopholes and is not sufficiently broad in scope to meet the requirements of consumer protection under modern conditions.

"The measure contains substantially all the features of the old law that have proved valuable in promoting honesty and fair dealing. But it amplifies and strengthens the provisions designed to safeguard the public health and prevent deception, and it extends the scope of the law to include cosmetics, therapeutic devices, and certain drugs that now escape regulation."

The report then lists the principal respects in which the measure differs from the Food and Drugs Act of 1906. Those relating wholly or partly to foods are:

"Reasonable sanitation is required in the production of foods, drugs, and cosmetics.

"Foods that are dangerous because of naturally contained poisons rather than added poisons are brought under regulation. The addition of poisons to foods is prohibited except where such addition is necessary or cannot be avoided; and in such cases tolerances are provided limiting the amount of added poison to the extent necessary to safeguard the public health.

"Where the other provisions of the measure are not effective to control danger to health arising from bacterial contamination of food, temporary license restrictions can be imposed until the difficulty is corrected.

"Definitions and standards of identity are provided under which the integrity of food products can be effectively maintained.

"Informative labeling of foods as to quality and composition is required for the information and guidance of consumers. Emphasis is placed on the informative labeling of special dietary foods, such as that for infants and invalids.

"The distinctive name proviso of the present law under which many debased and cheapened foods have escaped control is eliminated."

The Committee report then recites the new provisions applicable to drugs and continues with those applicable to all commodities subject to the law in the following statement:

"Authority is provided for inspection of factories making interstate shipments, without which the law could not be effectively enforced.

"Carriers are required to make available for copying, records showing interstate shipment of suspected articles so that Federal jurisdiction can be established.

"Increased penalties are provided for violations.

"Authority is given to the Federal Courts to restrain violations by injunction.

"These and other less important provisions are contained in the bill to make the measure effective for consumer protection without imposing unnecessary burdens on industry."

THE ADMINISTRATORS OF THE LAW

The Federal Food and Drugs Act of 1906 named the Secretary of Agriculture as its administrator. A unit of the Department of Agriculture, the Bureau of Chemistry, headed by Dr. Wiley until his resignation in 1912, was made the enforcing agency. On July 1, 1927, the Department set up a

new bureau, first called the Food, Drug and Insecticide Administration and later the Food and Drug Administration, to enforce the Food and Drugs Act, the Insecticide Act and certain other laws previously enforced by the Bureau of Chemistry. The Food, Drug, and Cosmetic Act of June 25, 1938, also named the Secretary of Agriculture as its administrator. The Food and Drug Administration remained the enforcing agency.

On June 30, 1940, under the President's Reorganization Plan No. IV, the Food and Drug Administration was transferred to the Federal Security Agency. The Federal Security Administrator then took over the enforcement responsibilities of the Secretary of Agriculture.

When by Act of Congress, effective April 11, 1953, the Federal Security Agency became the Department of Health, Education, and Welfare, the the Secretary of the new department became the administrator of the Food, Drug, and Cosmetics Act. The Food and Drug Administration continued as the enforcing agency.

AMENDMENTS TO THE LAW

The new law made instantly effective those provisions designed to protect the public against dangerous drugs, devices and cosmetics; it granted authority to begin immediately the formulation of necessary regulations, and continued in effect the provisions of the act of 1906 until the act of 1938 became fully effective. The act originally provided that it should become completely effective on June 25, 1939. An amendment approved June 23, 1939, however, postponed the new labeling requirements and certain other provisions until January 1, 1940.

Notwithstanding the long legislative consideration by Congress, court decisions revealed certain defects in the language of the law in the course of fifteen years of enforcement. Two of these created serious obstacles to effective consumer protection. Congress, however, promptly enacted corrective amendments. Other amendments were passed to meet new conditions growing out of revolutionary scientific progress in the drug field, especially in the development of antibiotic drugs.

Up to the end of the first session of the 83rd Congress, ten amendments to the Food, Drug, and Cosmetic Act, in addition to that postponing the effective date, were passed. One of these requires the testing and certification before distribution of drugs containing insulin, while four make similar requirements for some of the antibiotics; one amendment applies to prescription drugs; one authorizes assessing importers with the cost of certain supervisory work on imports; and one establishes controls over the distribution of colored oleomargarine.

One of the serious loopholes in the language of the law revealed by court decisions was closed by an amendment affirming Federal jurisdiction over products that become adulterated or misbranded after interstate shipment,

thus insuring the protection of the law over interstate products "all the way to the moment of their ultimate delivery to the consumer." The other legislative defect was corrected by an amendment defining and clarifying the government's authority to make factory inspections.

No less than nine bills proposing other amendments were pending at the adjournment of the first session of the 83rd Congress.*

The first fifteen years of enforcement have shown that in general the Food, Drug, and Cosmetic Act is remarkably adapted to meeting changing conditions in the regulated industries. The trend of the courts has been to construe the law liberally to give effect to the plain intent of Congress to make the statute an effective instrument of public protection. The Congress has been quick to respond by legislative action whenever a real need is shown.

DISCUSSION OF THE LAW BY SECTIONS

The Food, Drug, and Cosmetic Act is divided into nine chapters as follows: Chapter I—Short Title; II—Definitions; III—Prohibited Acts and Penalties; IV—Foods; V—Drugs and Devices; VI—Cosmetics; VII—General Administrative Provisions; VIII—Imports and Exports; IX—Miscellaneous.

Discussion of the terms of the law will be confined to those applicable to food products.

Chapter II—Definitions

This chapter defines "interstate commerce" as "(1) commerce between any State or Territory and any place outside thereof, and (2) commerce within the District of Columbia or within any other Territory not organized with a legislative body." It also defines the term "Territory" as any Territory or possession of the United States, including the District of Columbia and excluding the Canal Zone."

This language makes it clear that traffic in foods, drugs, therapeutic devices and cosmetics between the States, imports and exports, and commerce within the territories and the District of Columbia are subject to the law. Commerce beginning and ending within the borders of a single state is not subject to the Federal statute but only to the law of that state.

The last statement is subject to one exception. The amendment of March 16, 1950, regulates the sale of colored oleomargarine. At the time of its enactment, a separate amendment to the Internal Revenue Code stated "The Congress hereby finds and declares that the sale or the serving in public eating places, of colored oleomargarine or colored margarine without clear identification as such or which is otherwise adulterated or mis-

* *Ed. Note:* Since preparation of this manuscript, several amendments to the law have been passed. See Appendix, I-1.

branded within the meaning of the Federal Food, Drug, and Cosmetic Act depresses the market in interstate commerce for butter and for oleomargarine or margarine clearly identified and neither adulterated nor misbranded, and constitutes a burden on interstate commerce in such articles. Such burden exists, irrespective of whether such oleomargarine or margarine originates from an interstate source or from the State in which it is sold."

The oleomargarine legislation adheres closely to the judicial reasoning in numerous decisions defining the scope of Federal jurisdiction. Its constitutionality has not so far been challenged in the courts. Unless a contrary judicial interpretation is recorded, it must be assumed that the requirements of the Federal Food, Drug, and Cosmetic Act apply to colored oleomargarine even though it is manufactured and sold wholly within the boundaries of a single state.

Chapter II also defines the term "food" as "(1) articles used for food or drink for man or other animals, (2) chewing gum, and (3) articles used for components of any such article."

This comprehensive definition means that animal foods as well as foods for human beings are subject to the law and that components of foods, not actually in final form for consumption are within its purview. Chewing gum was included in the definition to forestall any possible contention that this article is technically not a food.

The definitions of the terms "label" and "labeling" are important because the law not only prohibits false and misleading labeling but also requires that certain positive information be given. The term "label" covers all written, printed or graphic matter on the immediate container. Whenever the law requires any word, statement, or other information to appear on the "label" this must be printed on the outside container or wrapper or be easily visible through the outside wrapper. The term "labeling" includes not only the outside label but also written, printed, or graphic matter which accompanies the article. Thus circulars, pictures and other printed matter enclosed in the retail package or printed upon or enclosed with the interstate shipping container are subject to the law. It is also now well settled that any labeling attached to an article while it is held for sale after shipment or delivery in interstate commerce is within the control of the act.

One more provision of Chapter II should be mentioned. It has particular application to drugs and therapeutic devices but has a direct bearing upon the labeling of foods for special dietary use. It states that "if an article is alleged to be misbranded because the labeling is misleading, then in determining whether the labeling is misleading there shall be taken into account (among other things) not only representations made or suggested by state-

ment, word, design, device, or any combination thereof, but also the extent to which the labeling fails to reveal facts material in the light of such representations or material with respect to consequences which may result from the use of the article to which the labeling relates under the conditions of use prescribed in the labeling thereof or under such conditions of use as are customary or usual."

Chapter III—Prohibited Acts and Penalties

The opening section prohibits certain specified acts including among others, the introduction of adulterated or misbranded articles in interstate commerce, the adulteration or misbranding of articles during or after interstate shipment, the refusal to make available records of interstate shipment or to permit factory inspection. Other prohibitions, all designed to protect consumers against adulterated or misbranded foods, drugs, and cosmetics are stated in clear terms.

This chapter authorizes three kinds of legal actions for the control of violations originating in the United States or its territories. Upon evidence supplied by the Secretary, the Department of Justice through the U. S. District Attorney may apply to the appropriate Federal Court for an injunction to restrain an offender from introducing adulterated or misbranded products into interstate commerce. If the evidence presented by the government is convincing, the court issues a formal order enjoining the individual against further offenses. Subsequent offenses make the offender liable to trial and fine or imprisonment for violation of the injunction.

The injunction procedure has been employed very successfully in halting the interstate shipment of foods from insanitary factories. An injunction is usually effective in bringing about a prompt correction of insanitary conditions.

The Government may also institute criminal prosecutions of alleged offenders. Trial is held in the Federal District Court, before a jury if one is demanded either by the defendant or by the government. The U. S. District Attorney presents the evidence of adulteration or misbranding through witnesses supplied by the Food and Drug Administration. Penalties upon first conviction may be as high as \$1,000 or imprisonment for not more than one year or both fine and imprisonment. For conviction on second and subsequent offenses the maximum penalty is set at \$10,000 and/or not more than three years imprisonment. The higher penalties may be imposed by the court even upon a first conviction if intent to defraud or mislead is charged and proved.

The deterrent and punitive effects of injunctions and criminal prosecutions are self evident. Consumer protection requires, however, that adulterated and misbranded products be promptly arrested before they can

reach the ultimate user. To provide such protection the law authorizes seizure of illegal goods.

Injunction proceedings and criminal prosecutions are instituted in the court of the district where the offender has his place of business; seizure actions are begun in the court of the judicial district where the goods are found. The Food and Drug Administration supplies information showing the location of the violative product and that it is in interstate commerce; it also gives details of the alleged adulteration and misbranding. The General Counsel of the Department of Health, Education and Welfare forwards this information to the District Attorney with a recommendation for seizure. To expedite action the records are usually sent directly to the District Attorney. However, when new or complex forms of violation are involved the records are sent to the Department of Justice for review. That Department, if it approves the proposed action, transmits them to the District Attorney. The Court then on motion of the District Attorney authorizes seizure action and directs the U. S. Marshal to take possession of the offending product.

In all instances, the owner of the goods, technically known as the claimant, has the right to file a claim to them and contest the government's charges in a formal trial. If he is successful, the property is released to him for unrestricted distribution. If the government prevails, the court may order the material destroyed or, if practicable, may permit the claimant to bring it into compliance with the law by relabeling or other means which will insure that only a legal product is eventually released for consumption. The claimant is required to do this at his own expense and under the supervision of the Food and Drug Administration.

Seizure action is the promptest, most effective and most frequently used method of protecting the American household against adulterated and misbranded foods. During the fiscal year ending June 30, 1953, the Food and Drug Administration caused seizure to be made of 1,220 shipments of adulterated or misbranded foods. In the same period 177 criminal prosecutions were instituted against manufacturers or shippers of violative foods and 6 injunctions against food producers were requested. The number of seizures instituted in any given period always exceeds the criminal prosecutions and injunctions. This is true because each shipment seized constitutes a separate violation of the law. When criminal prosecution is instituted the charges are so drawn as to cover all offenses committed by the manufacturer. In the case of injunctions also, it usually happens that a large number of seizures are necessary to clear the market of violative goods shipped prior to the issuance of the order of injunction.

Since the inspection and laboratory workers of the Food and Drug Administration are usually prepared to present incontrovertible evidence of the violations alleged in food seizures, only a small proportion of these

actions reach a formal court trial. In the majority of seizures the owner either abandons the goods for ultimate disposal by the court or admits the charge and obtains the court's permission to bring them into legal compliance, if this can be done, at his own expense under Food and Drug Administration supervision.

Before leaving this chapter mention should be made of a number of provisions designed to protect the proper interests of manufacturers and shippers. Before a criminal prosecution is instituted, an appropriate notice, known as a citation, must issue to the responsible party stating the details of the alleged offense and giving him an opportunity to present his views with regard to the proposed proceedings. These views which may be presented orally or in writing, in person or by attorney must be carefully considered by the Food and Drug Administration.

The answer may show that the cited party holds a legally valid guaranty from another firm from which he obtained the violative goods and that this certified them as complying with all the requirements of the law. Such a guaranty protects the cited party from prosecution but renders the guarantor liable to action. This is only one of the reasons which may be advanced in the course of a hearing which will justify the Food and Drug Administration in discontinuing the criminal prosecution. If valid reasons are not forthcoming, the Food and Drug Administration proceeds to the development of the case for reference to the courts.

The law also limits the government to seizure of only one shipment of a misbranded product unless the same misbranding charge has been confirmed by the court in a previous action; or unless the Secretary has cause to believe that the misbranded article is dangerous to health or that the labeling is fraudulent, or would be in a material respect misleading to the injury or damage of the purchaser or consumer. No such limitation on the number of seizures is made in the case of adulterated products. Where more than one seizure is made involving the same product, the same violation and the same claimant the actions may be consolidated for trial at one time and may be transferred for trial to a court of reasonable proximity to the claimant's principal place of business. A number of court decisions have established, however, that the claimant has no right under the law to the trial of a seizure action in his own judicial district.

Other provisions of the law permit the claimant to obtain samples from seized consignments and in some instances copies of the government's analyses and other data.

Chapter IV—Food

Definitions and Standards for Food. The consumer's overriding interest is recognized in the opening sentence which reads: "Whenever in the judgment of the Secretary such action will promote honesty and fair dealing

in the interest of consumers, he shall promulgate regulations fixing and establishing for any food, under its common or usual name so far as practicable, a reasonable definition and standard of identity, a reasonable standard of quality, and/or reasonable standards of fill of container." A proviso follows stating that no standards shall be established for fresh or dried fruits or vegetables or for butter, except that definitions and standards relating only to maturity and the effects of freezing may be established for avocados, cantaloupes, citrus fruits, and melons. The inclusion of butter in the list of excepted products is due undoubtedly to the fact that an act of Congress of March 4, 1923, defined butter. Committee reports are silent about the reasons for the other exceptions.

The food chapter of the statute contains no more important provisions than this authority to establish definitions and standards. The food industries and enforcing authorities have clearly recognized this. The formulation of definitions and standards has been a continuing project of the Food and Drug Administration ever since the enactment of the law. The industries and consumer groups have ably cooperated in this endeavor.

Standard making is, however, a complex and time consuming operation. The law in Chapter VII lays down specific directions for taking testimony at open hearings, for full publication at every step in the procedure and for court review in case a definition and standard as finally promulgated is challenged by an interested party. All of these provisions were designed by Congress to insure the legal validity of the definitions and standards.

Considering the complexity of the procedure and the long interruption of normal activities during World War II the Department has promulgated an impressive number of food definitions and standards. The definitions and standards are not static. They may be amended on the motion of industry or of the Secretary whenever the public interest requires.

The next two sections of the Food chapter define adulterated and misbranded foods. Here in plain terms are set forth what food manufacturers and distributors shall and shall not do to insure the purity, identity and honest, informative labeling of food.

Adulterated Food. Adulterations involving health hazards are dealt with first. Food is adulterated if it bears or contains any poisonous or deleterious substance which may render it injurious to health. Congress recognized, however, that some foods considered entirely wholesome, contain traces of substances unquestionably poisonous in larger amounts. Oxalic and hydrocyanic acids and their compounds, for example, naturally occur in harmless traces in some vegetables and fruits. To produce our edible crops, insecticides must be used to combat the destructive ravages of insects. This section provides, therefore, that a food naturally containing a poison shall not be considered adulterated if the quantity of such substance "does not ordinarily render it injurious to health." A later sec-

tion of the food chapter authorizes the Secretary to establish safe tolerances for unavoidable added poisons. Only if the food contains poisons in excess of such safe tolerances is it classed as adulterated.

The provisions which follow next have almost equal public health significance. They recognize that consumers have inborn and justifiable prejudices against insanitary practices in the preparation and handling of foods. A food is adulterated if it consists in whole or in part of any filthy, putrid or decomposed substance, or if it is otherwise unfit for food; if it has been prepared, packed, or held under insanitary conditions whereby it may have become contaminated with filth, or whereby it may have been rendered injurious to health; or if it is, in whole or in part, the product of a diseased animal or of an animal which has died otherwise than by slaughter; or if its container is composed, in whole or in part, of any poisonous or deleterious substance which may render the contents injurious to health.

By far the largest proportion of legal actions against adulterated foods are based on charges that they are in whole or in part filthy, putrid, or decomposed, or have been prepared packed or held under insanitary conditions. While insanitary practices in manufacturing plants account for many of these actions, a large number grow out of exposure of food, after interstate shipment, to the depredations of rodents, insects and spoilage organisms.

The next group of definitions of food adulteration relate to practices primarily affecting the consumer's pocketbook. They are essentially economic cheats, although indirectly health may be affected through debasement of nutritional values. A food is adulterated if a valuable constituent has been in whole or in part omitted or abstracted; if a substitution has occurred; if damage or inferiority has been concealed; or if any substance has been added to or mixed or packed therewith so as to increase its bulk or weight, or reduce its quality or strength, or make it appear better or of greater value than it is. Most of the forms of adulteration defined in this paragraph can be avoided by honest and informative labels, telling the whole truth about a product.

The next two paragraphs of the section defining adulterated foods are designed to protect consumer health. The first declares a food adulterated if it bears or contains a coal-tar color which has not been certified as safe and suitable for use. An exception permits the continued use of an uncertified color on citrus fruit "if application for listing of such color has been made under this act and such application has not been acted on by the Secretary, if such color was commonly used prior to the enactment of this Act for the purpose of coloring citrus fruit." A later section of the law authorizes the Secretary to issue a list of safe coal-tar colors and to establish a system of pretesting and certification of such colors before their sale.

The next paragraph relates to confectionery. It is adulterated if it "bears

or contains any alcohol or nonnutritive article or substance except harmless coloring, harmless flavoring, harmless resinous glaze not in excess of four-tenths of 1 per centum, natural gum and pectin: Provided that this paragraph shall not apply to any confectionery by reason of its containing less than one-half of 1 per centum by volume of alcohol derived solely from the use of flavoring extracts, or to any chewing gum by reason of its containing harmless nonnutritive masticatory substances."

Misbranded Food. The definitions of misbranding make it clear that misbranding may occur not alone through the use of false or misleading labeling, but also through failure to give adequate information to the purchaser. To buy food intelligently the consumer must be able to find easily on the label certain basic information about the product. The section on "Misbranded Foods" sets forth the sins of omission and of commission that constitute misbranding.

A food is misbranded if its labeling is false and misleading in any particular; if it is offered for sale under the name of another food; if it is an imitation and is not prominently labeled as such; if its container is so made, formed or filled as to be misleading.

It is also misbranded if the label fails to bear the name and place of business of the manufacturer, packer, or distributor and an accurate statement of the quantity of contents.

A food for which a definition and standard have been established is misbranded unless it conforms to the definition and standard. It must also be labeled with its recognized name and such other information as the standard requires: for example the names of optional ingredients permitted by the standard. If it falls below the established standard of quality or fill of container, the label must disclose this.

If no definition or standard has been established for a food, its label must give its common or usual name, if it has one, and if it is made up of more than one ingredient their common or usual names must be declared. Individual spices, flavors and colors need not be named separately but may be listed among the ingredients as spices, flavoring and coloring. A food containing artificial flavoring, artificial coloring or chemical preservative is misbranded unless this fact is declared.

The requirements of the misbranding section relating to food for special dietary use are entirely new in Federal food legislation and of great public health significance. The label must bear such information concerning its vitamin, mineral, and other dietary properties as the Secretary determines to be, and by regulations prescribes, as necessary fully to inform purchasers as to its value for such special dietary uses.

Evidence of the Congressional purpose to protect the consumer which pervades the entire act is again seen in a catchall provision which holds a food to be misbranded "if any word, statement, or information required by

or under authority of this Act to appear on the label or labeling is not prominently placed thereon with such conspicuousness (as compared with other statements, designs, or devices, in the labeling) and in such terms as to render it likely to be read and understood by the ordinary individual under customary conditions of purchase and use."

Emergency Permit Control. As the title implies this provision is designed for use in serious emergencies when foods are contaminated by dangerous microorganisms and the conventional methods of sampling and analysis cannot protect the public. In such circumstances, the Secretary is authorized to set up emergency control regulations and a temporary permit system. Manufacturers, processors and packers in the locality where the emergency exists may then ship in interstate commerce only if they hold permits which are issued only upon their compliance with the regulations. Operators are required to allow full inspection to permit the Secretary to determine whether the regulations have been met.

It is a commentary on the safety of modern food manufacturing processes that no occasion has arisen since the law was passed to invoke this authority.

Tolerances for Poisonous Ingredients in Food and Certification of Coal-Tar Colors for Food

The purposes of tolerances for poisonous ingredients has already been discussed in the Report of the House Committee on Interstate and Foreign Commerce and under the heading "Adulterated Food." This section has presented a complicated problem to the enforcing agency. While all poisonous substances which may occur unavoidably in foods are covered by its provisions, it is of particular importance in the control of spray residues on fruits and vegetables. As already pointed out poisonous sprays are our only defense against insects which would destroy our food supply if not held in check. The sprays must, however, be used with such restraint and precautions that the harvested crop is safe for food use.

A hearing was held by the Federal Security Agency in 1944 to take evidence on which to base tolerances for fluorine compounds. A regulation setting such a tolerance for fluorine-bearing residues on apples and pears was issued. This tolerance was invalidated when a Circuit Court of Appeals ruled that it was applicable only when fluorine was present as such and that it did not apply to compounds of fluorine: fluorine is never used except in combination with other elements.

War-time pressures prevented further activity in the development of tolerances. During the war, however, the chemical industries developed many new chemicals primarily for the protection of the armed forces against disease-bearing insects. Many of these proved to have great value as insecticides and fungicides on food crops.

Much research was carried on by the Food and Drug Administration,

other government bureaus and the manufacturers, on the value, toxicity and other properties of these substances. Not until 1950, however, was it possible to undertake tolerance hearings. A total of 255 witnesses was heard, including entomologists, plant pathologists, chemists, pharmacologists, horticulturists, economists, organic gardeners and a variety of other callings. Nine thousand pages of testimony with 1400 exhibits were accumulated.

This record, described by one writer as "the greatest collection of data ever assembled in one place in the history of the (insecticide) industry" represents a serious cooperative effort on the part both of industry and government to collect authentic data on which to base decisions on two broad questions: what chemicals are necessary on what crops; and what safe tolerances should be set up for these chemicals in or on foods.

The laborious task of abstracting the evidence and determining what tolerances must be incorporated in an order issued by the Secretary has occupied the time of the limited number of scientists available for the work since the completion of the hearing.

After approval and signature by the Secretary the order will be published in the Federal Register as a proposed regulation. Presumably a time limit will be set within which exceptions to the regulation may be filed. Exceptions will be thoroughly studied by the Secretary who may accept or reject them in whole or in part. After the necessary changes are made, a final order is published in the Federal Register. The usual practice is to make such an order effective 90 days after publication. Even after final publication, however, the law permits any party who may be adversely affected by the order to appeal, within 90 days after its issuance, for a court review.*

The course of tolerance making has been given in some detail as an example of most of the regulation making procedure required by the law. It may be stated that active consideration is now being given to possible legislation which will simplify the procedure without invalidating the resulting regulations.

The next paragraph of this section authorizes the Secretary to promulgate regulations listing coal-tar colors which are harmless and suitable for use in foods and for the testing and certification of batches of such colors, with or without harmless diluents, before their sale.

Colored Oleomargarine. Reference has already been made to the Act of Congress controlling colored oleomargarine. This is incorporated in the law as the last section of the chapter on Food. It requires that colored oleomargarine or colored margarine shall be retailed only in packages of one pound or less, shall be labeled with the word "oleomargarine" or "mar-

* *Ed. Note:* Since preparation of this manuscript, these tolerances have been published. See Appendix, I-1-H.

garine" in type at least as large as any other lettering on the label, and shall also be labeled with an accurate statement of all ingredients. All other labeling requirements of the law applicable to food must be observed. Wrapped subdivisions within a retail package must also carry the name in lettering not smaller than 20 point type.

Public eating places serving colored oleomargarine must post a prominent and easily readable notice to that effect or make a like declaration on the menu. Furthermore individual servings must be identified as oleomargarine by imprint on the serving itself or on the plate or dish or it must be served in a triangular shape.

Chapter VII—General Administrative Provisions

Regulations and Hearings. The first section of this chapter authorizes the Secretary to promulgate regulations for the efficient enforcement of the Act. It directs that the Secretaries of the Treasury and Health, Education and Welfare shall jointly set up regulations for the control of imports and exports.

It also prescribes the detailed procedure for the promulgation, repeal or amendment of regulations. This has been discussed to some extent in connection with definition and standard making and the establishment of tolerances. Adherence to the successive steps laid down in the law is essential if the regulations are to have legal force and effect. To repeat, the procedure calls for public hearings after ample advance public notice, and the formulation of orders based on the evidence so obtained. The order shall not take effect for at least 90 days unless the Secretary makes a finding that an emergency exists. All public notices are printed in the Federal Register.

In practice, the Secretary seldom publishes a regulation initially in the final form unless the subject matter is noncontroversial. Instead it is usual to issue a proposed order with an invitation for comments or suggestions within a specified time limit. The Secretary reviews these and may revise the order before final promulgation.

This section also contains the provision that permits any party adversely affected by an order to file within 90 days of its issuance a petition with the Circuit Court of Appeals for a judicial review of the order. The Court may consider the entire record as well as additional evidence and may affirm the order, or set it aside in whole or in part, temporarily or permanently. These Circuit Court decisions are subject to petition for review by the Supreme Court.

Examinations and Investigations. This section contains the authority for the Secretary to conduct the investigations and examinations necessary for the enforcement of the law. In practice this duty is assigned to the Food and Drug Administration but the Secretary may also commission

for this purpose any health, food or drug officer or employee of any State, territory or political subdivision. Through this means, the Food and Drug Administration has been able to promote effective cooperation with State and Municipal Enforcement officials. This has made for uniformity of action and has measurably enhanced public protection.

Provision is made in this part of the law for retaining a part of any sample collected to be made available upon request to the manufacturer, distributor or owner. The Secretary is permitted, however, to make reasonable exceptions to this requirement, as, for example, in the case of perishable foods.

Sea Food Inspection. This section, the only one of its kind in the Food Chapter, permits the Secretary upon the application of a packer of any sea food to station inspectors at the plant to examine and inspect the food, and to observe its production, packing and labeling. The packer pays the cost of the inspection. Sea foods packed under Food and Drug Administration inspection may be labeled to that effect. Shrimp and oyster packers are the only sea food packers who have taken advantage of their right to ask for governmental inspection. Since they must bear the cost of the inspection, their tendency is to discontinue the service after a period of inspection during which they learn how to apply for themselves the strict sanitary precautions enforced by the Food and Drug Administration's sea food inspectors. In the fiscal year ending June 30, 1953, 12 canners packed oysters under inspection; 9 of these also canned shrimp.

Records of Interstate Shipment. This section requires the holders of the necessary records proving that an article has been shipped in interstate commerce or otherwise brought within the jurisdiction of the law to make them available to the Secretary's representative.

Factory Inspection. This section, amended in 1953, after a judicial pronouncement invalidating the original language, authorizes inspectors upon presenting credentials and a written notice to enter, at reasonable times, any factory, warehouse, or establishment where foods, drugs, devices, and cosmetics are manufactured, processed, packed or held for introduction into interstate commerce or are held after such introduction or to enter any vehicle being used to transport or hold such goods in interstate commerce and to inspect them together with all pertinent equipment, finished and unfinished materials, containers and labeling. The inspector is required to report in writing to the owner, operator or agent in charge any conditions or practices he observes indicating that products in the establishment are in whole or in part filthy or are being prepared, packed or held under insanitary conditions whereby they may become contaminated with filth or rendered injurious. If the inspector collects food samples during the inspection and these are analyzed to determine whether they are in whole or in part filthy, putrid or decomposed or otherwise unfit for food, a report

of the analysis must be furnished the owner, operator, or agent in charge of the establishment. Such report, however, may not be used in labeling, advertising or other sales promotion.

Publicity. This section directs the Secretary to publish reports summarizing all judgments, decrees and court orders rendered under the act. This is done by means of so-called Notices of Judgment. During the fiscal year ending June 30, 1953, 1373 Notices of Judgment were published.

The Secretary is also authorized by this section to disseminate information regarding food, drugs, devices and cosmetics in situations involving imminent danger to health or gross deception. This authority is utilized in those fortunately rare instances when a dangerous product is so widely distributed that it cannot all be apprehended by the combined efforts of Federal, State and local authorities.

Chapter VIII—Imports and Exports

Imported articles are subject to the same requirements as to composition and labeling as those of domestic origin. Since foreign factories cannot be inspected, control is exercised by selective sampling and examination by the Food and Drug Administration at ports of entry.

Violative shipments are refused entry and required to be exported or destroyed. An exception is made, however, when the goods can be made entirely legal by relabeling or other procedure. The owner of the goods is held responsible for bringing them into compliance with the law: and he must bear all costs including those incurred by the government in maintaining surveillance and finally passing upon the legality of the product.

Exported products are treated very briefly in the law. They are not deemed adulterated or misbranded if they accord with the specifications of the foreign purchaser, do not conflict with the laws of the country to which they are consigned and are labeled on the shipping cases to show that they are for export. The force available to the Food and Drug Administration is too limited to permit supervision of exported products.

Chapter IX—Miscellaneous

The final chapter of the law sets the dates on which its various provisions became effective and contains provisions designed to harmonize and prevent conflict with other federal statutes covering the same or related commodities.

THE FOOD AND DRUG ADMINISTRATION

The administrative offices of the Food and Drug Administration are housed in the main building of the Department of Health, Education, and Welfare at 4th St. and Independence Ave. S. W., Washington, 25, D.C. Its

Washington laboratories occupy a portion of the South Building of the Department of Agriculture at 12th and C Sts., S.W.

The Commissioner of Food and Drugs is the directing head of the Administration. About 800 people are engaged in the law enforcement work with about 160 additional in the self-supporting certification services covering coal-tar colors, insulin, antibiotics and sea food packing. The personnel includes chemists, pharmacologists, physicians, bacteriologists, microanalysts, scientifically trained food and drug inspectors and the necessary clerical and sub-professional workers.

The Administration's appropriation for the year 1953-54 was \$5,200,000, a far from extravagant sum, considering that the organization is responsible for the safety, purity and honest labeling of the foods, drugs, cosmetics and therapeutic devices, both from interstate and import sources used by 160 million people.

The Food and Drug Administration is divided broadly into a Washington Staff and a Field Service. The former includes the commissioner's immediate administrative group, consisting of the deputy commissioner, two associate commissioners, a small staff of administrative assistants; also four administrative divisions entitled Program Research, Field Operations, State Cooperation and Regulatory Management; and eight technical divisions: Antibiotics, Cosmetics, Food, Medicine, Microbiology, Nutrition, Pharmaceutical Chemistry and Pharmacology.

The Field Service is strategically distributed to cover the entire country. To this end, the country is divided into sixteen Food and Drug Inspection Districts. A well-equipped laboratory staffed with the necessary scientific, inspectional and clerical personnel and directed by a District Chief is placed at a convenient city in each district. District headquarters are maintained at Atlanta, Baltimore, Boston, Buffalo, Chicago, Cincinnati, Denver, Kansas City, Los Angeles, Minneapolis, New Orleans, New York City, Philadelphia, St. Louis, San Francisco and Seattle.

The Food and Drug Administration can perform its complex task only through careful planning. In formulating its enforcement program, it must give first, and if necessary, exclusive attention to violations representing hazards to consumer health. Its planning must assure a uniform, even-handed administration of the law throughout the entire country. Fortunately foods that are dangerous because of the presence of poisons are rarely encountered. Foods that are adulterated through the use of filthy or decomposed raw materials, or through insanitary factory practices or exposure to contamination or spoilage at some stage in the journey to the consumer require much more regulatory attention. Offenses representing consumer cheats are given attention in the order of their importance. All the activities directed against violations in the food field must be balanced against the needs in the fields of drugs, cosmetics and therapeutic devices.

The Division of Program Research formulates well balanced plans for meeting these various obligations. The Division of Field Operations maintains general coordinating oversight over the Inspection Districts to see that the programs are effectively and uniformly carried out, that needed equipment is available and that personnel is properly trained and distributed. The Division of State Cooperation maintains contacts with State and local regulatory officers and facilitates their participation in the program. The Division of Regulatory Management takes charge of the collection of evidence and the assembling of witnesses to be used in court proceedings.

Food and drug law enforcement is never static. With the growth of scientific knowledge and manufacturing know-how new products appear. Vitamins, for example, were unknown when Congress was considering passage of the Food and Drugs Act of 1906. The changing times present new problems to the Food and Drug Administration. It must be ever alert to detect new forms of adulteration and misbranding.

A major duty of the Washington technical divisions is the development of new and improved laboratory methods for the detection of adulterated and misbranded products. These methods may be intended to detect some entirely novel type of adulteration or they may shorten the time required to complete an important analysis from days to hours or even minutes. The time element is highly important when the objective is to remove a hazardous product from the market with the utmost speed. As new methods are developed and their reliability proved, they are usually adopted as official by The Association of Official Agricultural Chemists. This Association is a private organization of American and Canadian food and drug enforcing scientists. Its official Book of Methods is widely used by all official chemists, although other methods may be used when necessary.

The Administration's Food Division devises new and improved methods for food analysis and plays a major part in collecting the scientific data needed as a basis for definitions and standards for foods. The Division of Microbiology applies microscopic and bacteriological techniques to the detection of adulteration.

The Division of Nutrition develops in its laboratories methods for the identification of vitamins and their quantitative estimation. It is, in fact, concerned with the entire field of nutritionally important food ingredients. The Division of Pharmacology has the important duty of evaluating the possible toxicity of substances which may occur in foods.

The Divisions of Medicine, Antibiotics, Cosmetics and Pharmaceutical Chemistry, as their names imply, are not so much concerned with the food field but may turn their attention to it in special cases. For example, The Division of Antibiotics, because of its familiarity with serological methods has been called upon to identify horse meat substituted for beef. The

Cosmetic Division which has as one of its duties the certification of coal-tar colors, may be called on to identify artificial colors in foods. The Microbiology and Pharmacology Divisions also do important work in the drug and cosmetic fields.

The Washington technical divisions also undertake highly specialized analyses for the Inspection Districts when the equipment needed is so complicated or expensive that it cannot be readily installed in the field laboratories.

The Food and Drug Inspection Districts are the front line in the war against adulteration and misbranding. The District Chiefs, following the general program, send their inspectors to factories, warehouses and other points where food is produced and stored. These trained observers are alert to discover evidence of violative practices. Consumer complaints and those from competing manufacturers of legal products are invariably investigated and frequently point the way to illegal acts. Today the vast majority of establishments manufacturing and distributing foods and other products subject to the law exercises scrupulous care to meet all its requirements. Even a small percentage of offenders among the many thousands of domestic concerns handling such products presents a formidable problem of regulatory control. In addition the Food and Drug Administration must maintain surveillance over imports at all ports and public eating places serving oleomargarine.

Once the inspector has observed practices suggesting adulteration or misbranding his next duty is to learn where interstate shipments are moving. The District Chief, if in his judgment legal action should be instituted, requests the District to which the goods are consigned to collect representative samples and records of interstate shipment. The samples are sent to the proper laboratory for analysis. If analysis confirms the suspicion of violation, the District Chief makes a preliminary decision as to what type of legal action should be taken.

If the violation represents a serious threat to consumer health or well-being he recommends seizure of the offending material. To insure speedy action a telegraphic report and a recommendation are forwarded to the Food and Drug Administration in Washington. If the recommendation is approved the necessary steps are taken there to effect immediate seizure. As an alternative to or in addition to seizure the District Chief may also conclude that criminal prosecution or injunction proceedings are in order. If prosecution is contemplated, he issues a notice of hearing to the responsible party setting a date on which the respondent may appear in person or by attorney, or may reply in writing to show cause why prosecution should not be instituted. After the hearing, the District Office forwards all records to the Administration in Washington with its recommendation as to appropriate action.

At this point, whether the action proposed by the Food and Drug Administration after a full review of the evidence is for seizure, criminal prosecution or injunction, the General Counsel of the Department of Health, Education, and Welfare and the Department of Justice enter the picture. The Food and Drug Administration's function is that of uncovering violations and collecting and evaluating the evidence. The General Counsel's office reviews the Administration's recommendation and if it agrees to the legal sufficiency of the evidence, prepares the necessary legal papers for transmission to the Department of Justice. That Department, if it concurs in the proposed action forwards the record to the proper U. S. District Attorney with instructions to institute legal proceedings. By agreement with the Department of Justice recommendations for seizure are usually sent directly by the General Counsel to the District Attorney, usually telegraphically to expedite action.

The details of court procedure have been sufficiently covered in the discussion of Chapter III of the law. It may be repeated, however, that in the event of a court contest, the Division of Regulatory Management marshals the evidence and arranges for the presence of the necessary witnesses to permit the District Attorney to present a convincing case.

In the fiscal year ending June 30, 1953, 276 criminal prosecutions based on traffic in adulterated or misbranded foods, drugs, devices and cosmetics were terminated in the courts. The fines paid, or assessed in cases pending on appeal, totaled \$146,578. The heaviest fine was \$10,000. In 45 cases the fines were \$1,000. or more. Jail sentences were imposed in 17 cases involving 19 defendants. The sentences ranged from 2 months to 1 year. For 15 defendants the jail sentences were suspended and they were placed on probation, a discretionary act of the court which effectively discourages repeated offenses.

The 1220 seizures of foods made during the same year included nearly 6,000 tons of decomposed or filth contaminated products. About one fourth of this had become unfit for use after it had been shipped by the producer. The volume of the Food and Drug Administration's work on foods is further shown by the following figures summarizing the year's activities: Inspection of food factories and warehouses, 9,982; food samples collected for examination, 15,297; food importations inspected and released, 25,420; food importations denied entry 4,030.

While decomposition and contamination with filth are a major cause of food adulterations, a survey of recent reports of the Food and Drug Administration reveals a wide variety of other causes of action. Among the many economic cheats that brought action were dressed turkeys with weights increased by stuffing the crops with as much as one and a quarter pounds of oats or by injecting up to a quart of water and then freezing. Oysters adulterated with added water are another example of the use of

this cheap and easily available adulterant. Other economic frauds include olive oil adulterated with as much as 80 per cent of cheaper food oil and cleverly manipulated to react like pure olive oil; horse meat substituted for beef; black pepper highly diluted with ground cereals. The inspection and laboratory work leading to the uncovering of some of these practices would make an interesting story if space permitted. Among adulterations of public health significance are wheat treated with a poisonous mercury compound for use as seed but diverted for milling; frozen clams containing a highly dangerous toxin produced by a microorganism in the waters where the clams had fed; wine containing a poisonous preservative; cheese penetrated by a similar preservative incorporated in the wrapping; dressed poultry containing diethylstilbestrol pellets imbedded in the edible portions of the necks; and apples bearing excessive residues of lead arsenate.

While tolerances for poisonous spray residues on fruits and vegetables have not yet been established, action may nevertheless be directed against shipments containing harmful residues under the general terms of the law. Fortunately, too, most producers carefully observe spraying schedules and formulas designed to protect their crops without leaving hazardous residues.

THE RESULTS OF FOOD LAW ENFORCEMENT

When Congress, in the early days of the twentieth Century was debating the legislation which finally became the Food and Drugs Act of 1906, comparatively few food manufacturers were farsighted enough to realize that careful manufacturers as well as consumers would be benefitted by the law. Yet in his Annual Report for 1917, the Chief of the Bureau of Chemistry, which then enforced the law, was able to say under the caption "Ten Years of the Food and Drugs Act:"

"The Food and Drugs Act was among the first of that group of laws which today would be classed as laws for the prevention of unfair competition. The suppression of fraud upon the consumer and of unfair competition among business rivals are but the two faces of the same coin. In consequence the food industries are sincerely and effectively supporting and helping the Bureau of Chemistry to enforce the law. Indeed, the bureau is not infrequently appealed to by the industries to compel the cessation of unfair practices and to encourage the standardization of products when the industry is incapable by itself of bringing about these results.

"The Act has been one of the influences which has helped to draw competitors together in associations like the guilds of the Middle Ages, associations shorn of special privileges which the ancient guilds often enjoyed. These associations have come to understand the value of constructive work and some of them devote considerable sums annually to experimental research designed to solve the technical problems with which the industry is con-

fronted. Thus, there is made available to the small manufacturer scientific assistance which would ordinarily be obtainable only by large corporations maintaining their own staff of investigators. Since the Bureau of Chemistry has always regarded it as its duty not merely to report violations of the law but also to prevent violations by constructive work intended to improve methods of manufacture, it cooperates actively with such associations of manufacturers. Such cooperation is bound to exert the profoundest influence on the country's industrial and social development."

If this was true after ten years of enforcement of the Act of 1906, it can be said much more emphatically after fifteen years of enforcement of the Act of 1938. During these fifteen years the process of transferring the preparation of our household foods from the home kitchen to the factory, begun at the turn of the century, has progressed with giant strides. Today, the housewife has available a variety of wholesome and acceptable foods, ready to serve with a minimum of kitchen preparation, undreamed of a score of years ago.

The program of industry research in the preparation and preservation of foods, noted by the Bureau of Chemistry in 1917, has been vastly expanded. As already noted the law of 1938 contained a new provision declaring a food adulterated if prepared, packed or held under insanitary conditions. Sanitary precautions have always been routinely observed by many food processing and handling plants, but the inclusion of the new provision in the law has made possible the application of regulatory pressure to the careless and slovenly establishment. The Annual Report of the Food and Drug Administration for 1950 states: "That the organized food industries are becoming increasingly conscious of sanitation is a gratifying sign of the times. National and local baking, milling, canning, dairy, and confectionery associations have attacked the problem of plant sanitation, directly and forcefully. Many establishments have engaged in extensive repair and reconstruction work to eliminate harborages or breeding places for insects and rodents. Systematic housekeeping programs for use by individual plants have been developed. Regular fumigation and rodent extermination programs are now the rule rather than the exception in plants doing an interstate business. These long-range sanitation programs are showing results in cleaner food for the consumer." The same report notes that in that year, of more than 77,000 food, drug and cosmetic firms manufacturing, shipping or storing interstate items, less than 2 per cent were implicated in seizures or criminal actions. "The safety of the nation's food supply," it states, "depends primarily on adequate controls and on full knowledge of the properties of every substance used in foods or in their growth and processing. Today's food industries have the will and the know-how to control manufacturing processes better than ever before."

Recent years have witnessed the formation of organizations of wider scope

than the associations serving the needs of single industries. The Nutrition Foundation, established in 1941 and supported through contributions by food manufacturers and distributors, promotes basic research and education in the science of nutrition through grants to universities and similar institutions.

In 1949, The Food Law Institute, Inc., was established through grants by members of the food industry "to develop the law of food through basic research and education." Its membership is made up of lawyers engaged in practice relating to the food laws of the United States and Canada. Counsel for the food industries and government attorneys participate in its deliberations. Its program includes not only constructive action in the way of supporting sound amendatory legislation when needed, but also in promoting the establishment of basic courses of instruction in the law in national law schools and other appropriate educational institutions. The Food Law Institute has published up to the end of 1953 five research books. The first was a compilation of the official annual reports on the Food and Drugs Act of 1906 and the Food, Drug, and Cosmetic Act of 1938 from 1907 to 1949 inclusive. The next three volumes compile the administrative and judicial record under the 1938 law from its enactment until January, 1953. The fifth book of the series covers "Canada's Food and Drug Laws." The Institute is also associated in the publication of the *Food, Drug and Cosmetic Law Journal*, a monthly devoted to current developments in food, drug and cosmetic laws and constructive professional discussion of them.

Mention should also be made of the pioneer Section of Food, Drug and Cosmetic Law in the New York State Bar Association and the subsequently organized Division of Food, Drug and Cosmetic Law in the American Bar Association's Section of Corporation, Banking and Business Law. Both of these legal groups were organized before The Food Law Institute and played an important part in promoting its foundation.

OFFICIAL PUBLICATIONS

The Food and Drug Administration's basic enforcement program rests on the conviction that most manufacturers have come to regard the law not merely as a code of legal obligation, but also as a moral code equally advantageous to themselves and to the consumers they serve. The Administration therefore extends the utmost cooperation to manufacturers seeking guidance in complying with the law. While it is without authority to approve formulas or labels (except to a limited extent under its certification services) it unhesitatingly offers constructive advice and criticism to manufacturers and distributors who seek such help in good faith. In this way a large degree of voluntary legal compliance is obtained without resort to legal action.

Publications are issued as guides to manufacturers on specific requirements. These can usually be obtained at a nominal price from the Superintendent of Documents, U.S. Government Printing Office, Washington, 25, D. C. and to a limited extent from The Food and Drug Administration.

The more important publications are:

“The Federal Register.” Published daily except Sundays, Mondays and days following Federal holidays. Contains legal notices, orders and regulations by all Federal agencies. Obtainable by subscription, or by single copies at varying prices, from Superintendent of Documents.

“The Federal Food, Drug, and Cosmetic Act and Regulations for its Enforcement, F.D.C. 1.” Single copies usually obtainable from the Food and Drug Administration. Obtainable from Superintendent of Documents for 20 cents in coin.

“Definitions and Standards for Foods, F.D.C. 2.” Inquire of Superintendent of Documents for prices of separates which give definitions and standards for each class of food so far standardized. Single copies of any class may be obtained from the Food and Drug Administration.

“Coal-Tar Color Regulations, F.D.C. 3.” Obtainable from Superintendent of Documents for 10 cents in coin.

“Import Requirements of the United States Food, Drug, and Cosmetic Act.” A Guide for Foreign Manufacturers and Shippers. Food and Drug Administration Miscellaneous Publication No. 2. Contains much information applicable to domestic products. Obtainable from Superintendent of Documents for 20 cents in coin.

“Read the Labels on Foods, Drugs, Devices and Cosmetics.” Food and Drug Administration Miscellaneous Publication No. 3. A consumer’s publication telling concisely with illustrations how the law protects the public. Obtainable from Superintendent of Documents for 15 cents in coin.

“Notices of Judgment under the Food, Drug, and Cosmetic Act.” Published in three series: Food, Drugs and Devices, Cosmetics. Apply to Food and Drug Administration designating series desired.

“Annual Report of the Food and Drug Administration.” Included in The Annual Reports of the Department of Health, Education and Welfare. The number printed is very limited. Inquire of Superintendent of Documents or Food and Drug Administration.



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APPENDIX

I. FOOD LAWS

1. FEDERAL FOOD, DRUG, AND COSMETIC ACT AND GENERAL REGULATIONS FOR ITS ENFORCEMENT

A. FEDERAL FOOD, DRUG, AND COSMETIC ACT, AS AMENDED AN ACT

To prohibit the movement in interstate commerce of adulterated and misbranded food, drugs, devices, and cosmetics, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

CHAPTER I—SHORT TITLE

SECTION 1. This Act may be cited as the Federal Food, Drug, and Cosmetic Act.

CHAPTER II—DEFINITIONS

SEC. 201. For the purposes of this Act—

(a) The term “Territory” means any Territory or possession of the United States, including the District of Columbia and excluding the Canal Zone.

(b) The term “interstate commerce” means (1) commerce between any State or Territory and any place outside thereof, and (2) commerce within the District of Columbia or within any other Territory not organized with a legislative body.

(c) The term “Department” means the U. S. Department of Health, Education, and Welfare.

(d) The term “Secretary” means the Secretary of Health, Education, and Welfare.

(e) The Term “person” includes individual, partnership, corporation, and association.

(f) The term “food” means (1) articles used for food or drink for man or other animals, (2) chewing gum, and (3) articles used for components of any such article.

(g) The term “drug” means (1) articles recognized in the official United States Pharmacopoeia, official Homoeopathic Pharmacopoeia of the United States, or official National Formulary, or any supplement to any of them; and (2) articles intended for use in the diagnosis, cure, mitigation, treatment, or prevention of disease in man or other animals; and (3) articles (other than food) intended to affect the structure or any function of the body of man or other animals; and (4) articles intended for use as a component of any articles specified in clause (1), (2), or (3); but does not include devices or their components, parts, or accessories.

(h) The term “device” (except when used in paragraph (n) of this section and in

sections 301 (i), 403 (f), 502 (c), and 602 (c)) means instruments, apparatus, and contrivances, including their components, parts, and accessories, intended (1) for use in the diagnosis, cure, mitigation, treatment, or prevention of disease in man or other animals; or (2) to affect the structure or any function of the body of man or other animals.

(i) The term "cosmetic" means (1) articles intended to be rubbed, poured, sprinkled, or sprayed on, introduced into, or otherwise applied to the human body or any part thereof for cleansing, beautifying, promoting attractiveness, or altering the appearance, and (2) articles intended for use as a component of any such articles; except that such term shall not include soap.

(j) The term "official compendium" means the official United States Pharmacopoeia, official Homoeopathic Pharmacopoeia of the United States, official National Formulary, or any supplement to any of them.

(k) The term "label" means a display of written, printed, or graphic matter upon the immediate container of any article; and a requirement made by or under authority of this Act that any word, statement, or other information appear on the label shall not be considered to be complied with unless such word, statement, or other information also appears on the outside container or wrapper, if any there be, of the retail package of such article, or is easily legible through the outside container or wrapper.

(l) The term "immediate container" does not include package liners.

(m) The term "labeling" means all labels and other written, printed, or graphic matter (1) upon any article or any of its containers or wrappers; or (2) accompanying such article.

(n) If an article is alleged to be misbranded because the labeling is misleading, then in determining whether the labeling is misleading there shall be taken into account (among other things) not only representations made or suggested by statement, word, design, device, or any combination thereof, but also the extent to which the labeling fails to reveal facts material in the light of such representations or material with respect to consequences which may result from the use of the article to which the labeling relates under the conditions of use prescribed in the labeling thereof or under such conditions of use as are customary or usual.

(o) The representation of a drug, in its labeling, as an antiseptic shall be considered to be a representation that it is a germicide, except in the case of a drug purporting to be, or represented as, an antiseptic for inhibitory use as a wet dressing, ointment, dusting powder, or such other use as involves prolonged contact with the body.

(p) The term "new drug" means—

(1) Any drug the composition of which is such that such drug is not generally recognized, among experts qualified by scientific training and experience to evaluate the safety of drugs, as safe for use under the conditions prescribed, recommended, or suggested in the labeling thereof, except that such a drug not so recognized shall not be deemed to be a "new drug" if at any time prior to the enactment of this Act it was subject to the Food and Drugs Act of June 30, 1906, as amended, and if at such time its labeling contained the same representations concerning the conditions of its use; or

(2) Any drug the composition of which is such that such drug, as a result of investigations to determine its safety for use under such conditions, has become so recognized, but which has not, otherwise than in such investigations, been used to a material extent or for a material time under such conditions.

[The following additional definitions for food are provided for in other acts:

Sec. 201a. Butter. The Act of March 4, 1923 (42 Stat. 1500), defines butter as "For the purposes of this chapter 'butter' shall be understood to mean the food product usually known as butter, and which is made exclusively from milk or cream, or both, with or with-

out common salt, and with or without additional coloring matter, and containing not less than 80 per centum by weight of milk fat, all tolerances having been allowed for."

Sec. 201b. Package. The Act of July 24, 1919 (31 Stat. 271), declares "The word 'package' where it occurs in this chapter shall include and shall be construed to include wrapped meats inclosed in papers or other materials as prepared by the manufacturers thereof for sale."

Sec. 201c. Nonfat Dry Milk Solids. The Act of March 2, 1944 (58 Stat. 108), defines nonfat dry milk solids as follows: "For the purposes of this chapter, nonfat dry milk solids or defatted milk solids is the product resulting from the removal of fat and water from milk, and contains the lactose, milk proteins, and milk minerals in the same relative proportions as in the fresh milk from which made. It contains not over 5 per centum by weight of moisture. The fat content is not over 1½ per centum by weight unless otherwise indicated. The term 'milk' when used herein, means sweet milk of cows."

See page 891 for definition of oleomargarine.]

CHAPTER III—PROHIBITED ACTS AND PENALTIES

Prohibited Acts

SEC. 301. The following acts and the causing thereof are hereby prohibited:

(a) The introduction or delivery for introduction into interstate commerce of any food, drug, device, or cosmetic that is adulterated or misbranded.

(b) The adulteration or misbranding of any food, drug, device, or cosmetic in interstate commerce.

(c) The receipt in interstate commerce of any food, drug, device, or cosmetic that is adulterated or misbranded, and the delivery or proffered delivery thereof for pay or otherwise.

(d) The introduction or delivery for introduction into interstate commerce of any article in violation of section 404 or 505.

(e) The refusal to permit access to or copying of any record as required by section 703.

(f) The refusal to permit entry or inspection as authorized by section 704.

(g) The manufacture within any Territory of any food, drug, device, or cosmetic that is adulterated or misbranded.

(h) The giving of a guaranty or undertaking referred to in section 303 (c) (2), which guaranty or undertaking is false, except by a person who relied upon a guaranty or undertaking to the same effect signed by, and containing the name and address of, the person residing in the United States from whom he received in good faith the food, drug, device, or cosmetic; or the giving of a guaranty or undertaking referred to in section 303 (c) (3), which guaranty or undertaking is false.

(i) Forging, counterfeiting, simulating, or falsely representing, or without proper authority using any mark, stamp, tag, label, or other identification device authorized or required by regulations promulgated under the provisions of section 404, 406 (b), 504, 506, 507, or 604.

(j) The using by any person to his own advantage, or revealing, other than to the Secretary or officers or employees of the Department, or to the courts when relevant in any judicial proceeding under this Act, any information acquired under authority of section 404, 505, 506, 507, or 704 concerning any method or process which as a trade secret is entitled to protection.

(k) The alteration, mutilation, destruction, obliteration, or removal of the whole or any part of the labeling of, or the doing of any other act with respect to, a food, drug, device, or cosmetic, if such act is done while such article is held for sale (whether

Approved August 7, 1953.

or not the first sale) after shipment in interstate commerce and results in such article being adulterated or misbranded.

(l) The using, on the labeling of any drug or in any advertising relating to such drug, of any representation or suggestion that an application with respect to such drug is effective under section 505, or that such drug complies with the provisions of such section.

(m) The sale or offering for sale of colored oleomargarine or colored margarine, or the possession or serving of colored oleomargarine or colored margarine in violation of sections 407 (b), or 407 (c).

(n) The using, in labeling, advertising or other sales promotion of any reference to any report or analysis furnished in compliance with section 704.

Injunction Proceedings

SEC. 302. (a) The district courts of the United States and the United States courts of the Territories shall have jurisdiction, for cause shown, and subject to the provisions of section 17 (relating to notice to opposite party) of the Act entitled "An Act to supplement existing laws against unlawful restraints and monopolies, and for other purposes," approved October 15, 1914, as amended, to restrain violations of section 301, except paragraphs (e), (f), (h), (i), and (j). [This section, which appeared as U. S. C., title 28, sec. 381, has been repealed. It is now covered by Civil Proc. R. 65.]

(b) In case of violation of an injunction or restraining order issued under this section, which also constitutes a violation of this Act, trial shall be by the court, or, upon demand of the accused, by a jury. Such trial shall be conducted in accordance with the practice and procedure applicable in the case of proceedings subject to the provisions of section 22 of such Act, of October 15, 1914, as amended. [This section is now covered by U. S. C., title 18, sec. 402.]

Penalties

SEC. 303. (a) Any person who violates any of the provisions of section 301 shall be guilty of a misdemeanor and shall on conviction thereof be subject to imprisonment for not more than one year, or a fine of not more than \$1,000, or both such imprisonment and fine; but if the violation is committed after a conviction of such person under this section has become final such person shall be subject to imprisonment for not more than three years, or a fine of not more than \$10,000, or both such imprisonment and fine.

(b) Notwithstanding the provisions of subsection (a) of this section, in case of a violation of any of the provisions of section 301, with intent to defraud or mislead, the penalty shall be imprisonment for not more than three years, or a fine of not more than \$10,000, or both such imprisonment and fine.

(c) No person shall be subject to the penalties of subsection (a) of this section, (1) for having received in interstate commerce any article and delivered it or proffered delivery of it, if such delivery or proffer was made in good faith, unless he refuses to furnish on request of an officer or employee duly designated by the Secretary the name and address of the person from whom he purchased or received such article and copies of all documents, if any there be, pertaining to the delivery of the article to him; or (2) for having violated section 301 (a) or (d), if he establishes a guaranty or undertaking signed by, and containing the name and address of, the person residing in the United States from whom he received in good faith the article, to the effect, in case of an alleged violation of section 301 (a), that such article is not adulterated

or misbranded, within the meaning of this Act, designating this Act, or to the effect, in case of an alleged violation of section 301 (d), that such article is not an article which may not, under the provisions of section 404 or 505, be introduced into interstate commerce; or (3) for having violated section 301 (a), where the violation exists because the article is adulterated by reason of containing a coal-tar color not from a batch certified in accordance with regulations promulgated by the Secretary under this Act, if such person establishes a guaranty or undertaking signed by, and containing the name and address of, the manufacturer of the coal-tar color, to the effect that such color was from a batch certified in accordance with the applicable regulations promulgated by the Secretary under this Act; or (4) for having violated section 301 (b), (c) or (k) by failure to comply with section 502 (f) in respect to an article received in interstate commerce to which neither section 503 (a) nor section 503 (b) (1) is applicable, if the delivery or proffered delivery was made in good faith and the labeling at the time thereof contained the same directions for use and warning statements as were contained in the labeling at the time of such receipt of such article.

Seizure

SEC. 304. (a) Any article of food, drug, device, or cosmetic that is adulterated or misbranded when introduced into or while in interstate commerce or while held for sale (whether or not the first sale) after shipment in interstate commerce, or which may not, under the provisions of section 404 or 505, be introduced into interstate commerce, shall be liable to be proceeded against while in interstate commerce, or at any time thereafter, on libel of information and condemned in any district court of the United States within the jurisdiction of which the article is found: *Provided, however,* That no libel for condemnation shall be instituted under this Act, for any alleged misbranding if there is pending in any court a libel for condemnation proceeding under this Act based upon the same alleged misbranding, and not more than one such proceeding shall be instituted if no such proceeding is so pending, except that such limitations shall not apply (1) when such misbranding has been the basis of a prior judgment in favor of the United States, in a criminal, injunction, or libel for condemnation proceeding under this Act or (2) when the Secretary has probable cause to believe from facts found, without hearing, by him or any officer or employee of the Department that the misbranded article is dangerous to health, or that the labeling of the misbranded article is fraudulent, or would be in a material respect misleading to the injury or damage of the purchaser or consumer. In any case where the number of libel for condemnation proceedings is limited as above provided the proceeding pending or instituted shall, on application of the claimant, seasonably made, be removed for trial to any district agreed upon by stipulation between the parties, or, in case of failure to so stipulate within a reasonable time, the claimant may apply to the court of the district in which the seizure has been made, and such court (after giving the United States attorney for such district reasonable notice and opportunity to be heard) shall by order, unless good cause to the contrary is shown, specify a district of reasonable proximity to the claimant's principal place of business to which the case shall be removed for trial.

(b) The article shall be liable to seizure by process pursuant to the libel, and the procedure in cases under this section shall conform, as nearly as may be, to the procedure in admiralty; except that on demand of either party any issue of fact joined in any such case shall be tried by jury. When libel for condemnation proceedings under this section, involving the same claimant and the same issues of adulteration or misbranding, are pending in two or more jurisdictions, such pending proceedings,

upon application of the claimant seasonably made to the court of one such jurisdiction, shall be consolidated for trial by order of such court, and tried in (1) any district selected by the claimant where one of such proceedings is pending; or (2) a district agreed upon by stipulation between the parties. If no order for consolidation is so made within a reasonable time, the claimant may apply to the court of one such jurisdiction, and such court (after giving the United States attorney for such district reasonable notice and opportunity to be heard) shall by order, unless good cause to the contrary is shown, specify a district of reasonable proximity to the claimant's principal place of business, in which all such pending proceedings shall be consolidated for trial and tried. Such order of consolidation shall not apply so as to require the removal of any case the date for trial of which has been fixed. The court granting such order shall give prompt notification thereof to the other courts having jurisdiction of the cases covered thereby.

"(c) The court at any time after seizure up to a reasonable time before trial shall by order allow any part to a condemnation proceeding, his attorney or agent, to obtain a representative sample of the article seized and a true copy of the analysis, if any, on which the proceeding is based and the identifying marks or numbers, if any, of the packages from which the samples analyzed were obtained."

(d) Any food, drug, device, or cosmetic condemned under this section shall, after entry of the decree, be disposed of by destruction or sale as the court may, in accordance with the provisions of this section, direct and the proceeds thereof, if sold, less the legal costs and charges, shall be paid into the Treasury of the United States; but such article shall not be sold under such decree contrary to the provisions of this Act or the laws of the jurisdiction in which sold: *Provided*, That after entry of the decree and upon the payment of the costs of such proceedings and the execution of a good and sufficient bond conditioned that such article shall not be sold or disposed of contrary to the provisions of this Act or the laws of any State or Territory in which sold, the court may by order direct that such article be delivered to the owner thereof to be destroyed or brought into compliance with the provisions of this Act under the supervision of an officer or employee duly designated by the Secretary, and the expenses of such supervision shall be paid by the person obtaining release of the article under bond. Any article condemned by reason of its being an article which may not, under section 404 or 505, be introduced into interstate commerce, shall be disposed of by destruction.

(e) When a decree of condemnation is entered against the article, court costs and fees, and storage and other proper expenses, shall be awarded against the person, if any, intervening as claimant of the article.

(f) In the case of removal for trial of any case as provided by subsection (a) or (b)—

(1) The clerk of the court from which removal is made shall promptly transmit to the court in which the case is to be tried all records in the case necessary in order that such court may exercise jurisdiction.

(2) The court to which such case was removed shall have the powers and be subject to the duties, for purposes of such case, which the court from which removal was made would have had, or to which such court would have been subject, if such case had not been removed.

Hearing before Report of Criminal Violation

SEC. 305. Before any violation of this Act is reported by the Secretary to any United States attorney for institution of a criminal proceeding, the person against whom

such proceeding is contemplated shall be given appropriate notice and an opportunity to present his views, either orally or in writing, with regard to such contemplated proceeding.

Report of Minor Violations

SEC. 306. Nothing in this Act shall be construed as requiring the Secretary to report for prosecution, or for the institution of libel or injunction proceedings, minor violations of this Act whenever he believes that the public interest will be adequately served by a suitable written notice or warning.

Proceedings in Name of United States; Provision as to Subpenas

SEC. 307. All such proceedings for the enforcement, or to restrain violations, of this Act shall be by and in the name of the United States. Notwithstanding the provisions of section 876 of the Revised Statutes, subpenas for witnesses who are required to attend a court of the United States, in any district, may run into any other district in any such proceeding.

CHAPTER IV—FOOD

Definitions and Standards for Food

SEC. 401. (a) Whenever in the judgment of the Secretary such action will promote honesty and fair dealing in the interest of consumers, he shall promulgate regulations¹ fixing and establishing for any food, under its common or usual name so far as practicable, a reasonable definition and standard of identity, a reasonable standard of quality, and/or reasonable standards of fill of container: *Provided*, That no definition and standard of identity and no standard of quality shall be established for fresh or dried fruits, fresh or dried vegetables, or butter, except that definitions and standards of identity may be established for avocados, cantaloupes, citrus fruits, and melons. In prescribing any standard of fill of container, the Secretary shall give due consideration to the natural shrinkage in storage and in transit of fresh natural food and to need for the necessary packing and protective material. In the prescribing of any standard of quality for any canned fruit or canned vegetable, consideration shall be given and due allowance made for the differing characteristics of the several varieties of such fruit or vegetable. In prescribing a definition and standard of identity for any food or class of food in which optional ingredients are permitted, the Secretary shall, for the purpose of promoting honesty and fair dealing in the interest of consumers, designate the optional ingredients which shall be named on the label. Any definition and standard of identity prescribed by the Secretary for avocados, cantaloupes, citrus fruits, or melons shall relate only to maturity and to the effects of freezing.

Adulterated Food

SEC. 402. A food shall be deemed to be adulterated—

(a) (1) If it bears or contains any poisonous or deleterious substance which may render it injurious to health; but in case the substance is not an added substance such food shall not be considered adulterated under this clause if the quantity of such substance in such food does not ordinarily render it injurious to health; or (2) if it

¹ 21 CFR, Parts 10–53. Service and Regulatory Announcements, Food, Drug, and Cosmetic No. 2; Separate Parts, according to subject.

bears or contains any added poisonous or added deleterious substance which is unsafe within the meaning of section 406; or (3) if it consists in whole or in part of any filthy, putrid, or decomposed substance, or if it is otherwise unfit for food; or (4) if it has been prepared, packed, or held under insanitary conditions whereby it may have become contaminated with filth, or whereby it may have been rendered injurious to health; or (5) if it is, in whole or in part, the product of a diseased animal or of an animal which has died otherwise than by slaughter; or (6) if its container is composed, in whole or in part, of any poisonous or deleterious substance which may render the contents injurious to health.

(b) (1) If any valuable constituent has been in whole or in part omitted or abstracted therefrom; or (2) if any substance has been substituted wholly or in part therefor; or (3) if damage or inferiority has been concealed in any manner; or (4) if any substance has been added thereto or mixed or packed therewith so as to increase its bulk or weight, or reduce its quality or strength, or make it appear better or of greater value than it is.

(c) If it bears or contains a coal-tar color other than one from a batch that has been certified in accordance with regulations as provided by section 406: *Provided*, That this paragraph shall not apply to citrus fruit bearing or containing a coal-tar color if application for listing of such color has been made under this Act and such application has not been acted on by the Secretary, if such color was commonly used prior to the enactment of this Act for the purpose of coloring citrus fruit.

(d) If it is confectionery, and it bears or contains any alcohol or nonnutritive article or substance except harmless coloring, harmless flavoring, harmless resinous glaze not in excess of four-tenths of 1 per centum, natural gum, and pectin: *Provided*, That this paragraph shall not apply to any confectionery by reason of its containing less than one-half of 1 per centum by volume of alcohol derived solely from the use of flavoring extracts, or to any chewing gum by reason of its containing harmless non-nutritive masticatory substances.

(e) If it is oleomargarine or margarine or butter and any of the raw material used therein consisted in whole or in part of any filthy, putrid, or decomposed substance, or such oleomargarine or margarine or butter is otherwise unfit for food.

Misbranded Food

SEC. 403. A food shall be deemed to be misbranded—

(a) If its labeling is false or misleading in any particular.

(b) If it is offered for sale under the name of another food.

(c) If it is an imitation of another food, unless its label bears, in type of uniform size and prominence, the word "imitation" and, immediately thereafter, the name of the food imitated.

(d) If its container is so made, formed, or filled as to be misleading.

(e) If in package form unless it bears a label containing (1) the name and place of business of the manufacturer, packer, or distributor; and (2) an accurate statement of the quantity of the contents in terms of weight, measure, or numerical count: *Provided*, That under clause (2) of this paragraph reasonable variations shall be permitted, and exemptions as to small packages shall be established, by regulations prescribed by the Secretary.

(f) If any word, statement, or other information required by or under authority of this Act to appear on the label or labeling is not prominently placed thereon with such conspicuousness (as compared with other words, statements, designs, or devices, in the labeling) and in such terms as to render it likely to be read and understood by the ordinary individual under customary conditions of purchase and use.

(g) If it purports to be or is represented as a food for which a definition and standard of identity has been prescribed by regulations as provided by section 401, unless (1) it conforms to such definition and standard, and (2) its label bears the name of the food specified in the definition and standard, and, insofar as may be required by such regulations, the common names of optional ingredients (other than spices, flavoring, and coloring) present in such food.

(h) If it purports to be or is represented as—

(1) a food for which a standard of quality has been prescribed by regulations as provided by section 401, and its quality falls below such standard, unless its label bears, in such manner and form as such regulations specify, a statement that it falls below such standard; or

(2) a food for which a standard or standards of fill of container have been prescribed by regulations as provided by section 401, and it falls below the standard of fill of container applicable thereto, unless its label bears, in such manner and form as such regulations specify, a statement that it falls below such standard.

(i) If it is not subject to the provisions of paragraph (g) of this section unless its label bears (1) the common or usual name of the food, if any there be, and (2) in case it is fabricated from two or more ingredients, the common or usual name of each such ingredient; except that spices, flavorings, and colorings, other than those sold as such, may be designated as spices, flavorings, and colorings without naming each: *Provided*, That, to the extent that compliance with the requirements of clause (2) of this paragraph is impracticable, or results in deception or unfair competition, exemptions shall be established by regulations promulgated by the Secretary.

(j) If it purports to be or is represented for special dietary uses, unless its label bears such information concerning its vitamin, mineral, and other dietary properties as the Secretary determines to be, and by regulations² prescribes as, necessary in order fully to inform purchasers as to its value for such uses.

(k) If it bears or contains any artificial flavoring, artificial coloring, or chemical preservative, unless it bears labeling stating that fact: *Provided*, That to the extent that compliance with the requirements of this paragraph is impracticable, exemptions shall be established by regulations promulgated by the Secretary. The provisions of this paragraph and paragraphs (g) and (i) with respect to artificial coloring shall not apply in the case of butter, cheese, or ice cream.

Emergency Permit Control

SEC. 404. (a) Whenever the Secretary finds after investigation that the distribution in interstate commerce of any class of food may, by reason of contamination with micro-organisms during the manufacture, processing, or packing thereof in any locality, be injurious to health, and that such injurious nature cannot be adequately determined after such articles have entered interstate commerce, he then, and in such case only, shall promulgate regulations providing for the issuance, to manufacturers, processors, or packers of such class of food in such locality, of permits to which shall be attached such conditions governing the manufacture, processing, or packing of such class of food, for such temporary period of time, as may be necessary to protect the public health; and after the effective date of such regulations, and during such temporary period, no person shall introduce or deliver for introduction into interstate commerce any such food manufactured, processed, or packed by any such manufacturer, processor, or packer unless such manufacturer, processor, or packer holds a permit issued by the Secretary as provided by such regulations.

² 21 CFR, 125.1 *et seq.*

(b) The Secretary is authorized to suspend immediately upon notice any permit issued under authority of this section if it is found that any of the conditions of the permit have been violated. The holder of a permit so suspended shall be privileged at any time to apply for the reinstatement of such permit, and the Secretary shall, immediately after prompt hearing and an inspection of the establishment, reinstate such permit if it is found that adequate measures have been taken to comply with and maintain the conditions of the permit, as originally issued or as amended.

(c) Any officer or employee duly designated by the Secretary shall have access to any factory or establishment, the operator of which holds a permit from the Secretary, for the purpose of ascertaining whether or not the conditions of the permit are being complied with, and denial of access for such inspection shall be ground for suspension of the permit until such access is freely given by the operator.

Regulations Making Exemptions

SEC. 405. The Secretary shall promulgate regulations exempting from any labeling requirement of this Act (1) small open containers of fresh fruits and fresh vegetables and (2) food which is, in accordance with the practice of the trade, to be processed, labeled, or repacked in substantial quantities at establishments other than those where originally processed or packed, on condition that such food is not adulterated or misbranded under the provisions of this Act upon removal from such processing, labeling, or repacking establishment.

Tolerances for Poisonous Ingredients in Food and Certification of Coal-Tar Colors for Food

SEC. 406. (a) Any poisonous or deleterious substance added to any food, except where such substance is required in the production thereof or cannot be avoided by good manufacturing practice shall be deemed to be unsafe for purposes of the application of clause (2) of section 402) (a); but when such substance is so required or cannot be so avoided, the Secretary shall promulgate regulations³ limiting the quantity therein or thereon to such extent as he finds necessary for the protection of public health, and any quantity exceeding the limits so fixed shall also be deemed to be unsafe for purposes of the application of clause (2) of section 402 (a). While such a regulation is in effect limiting the quantity of any such substance in the case of any food, such food shall not, by reason of bearing or containing any added amount of such substance, be considered to be adulterated within the meaning of clause (1) of section 402 (a). In determining the quantity of such added substance to be tolerated in or on different articles of food the Secretary shall take into account the extent to which the use of such substance is required or cannot be avoided in the production of each such article, and the other ways in which the consumer may be affected by the same or other poisonous or deleterious substances.

(b) The Secretary shall promulgate regulations providing for the listing of coal-tar colors⁴ which are harmless and suitable for use in food and for the certification of batches of such colors, with or without harmless diluents.

Oleomargarine or Margarine

[Public Law 459—81st Congress—March 16, 1950 (64 Stat. 20), amended section 15 of the Federal Trade Commission Act, As Amended, by adding at the end thereof the follow-

³ 21 CFR, 120.1 *et seq.*

⁴ 21 CFR 135.1 *et seq.*; Service and Regulatory Announcements, Food, Drug, and Cosmetic No. 3.

ing new subsection: "(f) For the purposes of this section and section 407 of the Federal Food, Drug, and Cosmetic Act, As Amended, the term 'oleomargarine' or 'margarine' includes—(1) all substances, mixtures, and compounds known as oleomargarine or margarine; (2) all substances, mixtures, and compounds which have a consistence similar to that of butter and which contain any edible oils or fats other than milk fat if made in imitation or semblance of butter."

In repealing section 2301 of the Internal Revenue Code (relating to the tax on oleomargarine) Public Law 459 declared, in part: "The Congress hereby finds and declares that the sale, or the serving in public eating places, of colored oleomargarine or colored margarine without clear identification as such or which is otherwise adulterated or misbranded within the meaning of the Federal Food, Drug, and Cosmetic Act depresses the market in interstate commerce for butter and for oleomargarine or margarine clearly identified and neither adulterated nor misbranded, and constitutes a burden on interstate commerce in such articles. Such burden exists, irrespective of whether such oleomargarine or margarine originates from an interstate source or from the State in which it is sold."

"Nothing in this Act shall be construed as authorizing the possession, sale, or serving of colored oleomargarine or colored margarine in any State or Territory in contravention of the laws of such State or Territory."]

SEC. 407 (a). Colored oleomargarine or colored margarine which is sold in the same State or Territory in which it is produced shall be subject in the same manner and to the same extent to the provisions of this Act as if it had been introduced in interstate commerce.

(b) No person shall sell, or offer for sale, colored oleomargarine or colored margarine unless—

- (1) such oleomargarine is packaged,
- (2) the net weight of the contents of any package sold in a retail establishment is one pound or less,
- (3) there appears on the label of the package (A) the word "oleomargarine" or "margarine" in type or lettering at least as large as any other type or lettering on such label, and (B) a full and accurate statement of all the ingredients contained in such oleomargarine or margarine, and
- (4) each part of the contents of the package is contained in a wrapper which bears the word "oleomargarine" or "margarine" in type or lettering not smaller than 20-point type.

The requirements of this subsection shall be in addition to and not in lieu of any of the other requirements of this Act.

(c) No person shall possess in a form ready for serving colored oleomargarine or colored margarine at a public eating place unless a notice that oleomargarine or margarine is served is displayed prominently and conspicuously in such place and in such manner as to render it likely to be read and understood by the ordinary individual being served in such eating place or is printed or is otherwise set forth on the menu in type or lettering not smaller than that normally used to designate the serving of other food items. No person shall serve colored oleomargarine or colored margarine at a public eating place, whether or not any charge is made therefor, unless (1) each separate serving bears or is accompanied by labeling identifying it as oleomargarine or margarine, or (2) each separate serving thereof is triangular in shape.

(d) Colored oleomargarine or colored margarine when served with meals at a public eating place shall at the time of such service be exempt from the labeling requirements of section 403 (except (a) and 403 (f)) if it complies with the requirements of subsection (b) of this section.

(e) For the purpose of this section colored oleomargarine or colored margarine is oleomargarine or margarine having a tint or shade containing more than one and six-tenths degrees of yellow, or of yellow and red collectively, but with an excess of yellow over red, measured in terms of Lovibond tintometer scale or its equivalent.

CHAPTER V—DRUGS AND DEVICES

Adulterated Drugs and Devices

SEC. 501. A drug or device shall be deemed to be adulterated—

(a) (1) If it consists in whole or in part of any filthy, putrid, or decomposed substance; or (2) if it has been prepared, packed, or held under insanitary conditions whereby it may have been contaminated with filth, or whereby it may have been rendered injurious to health; or (3) if it is a drug and its container is composed, in whole or in part, of any poisonous or deleterious substance which may render the contents injurious to health; or (4) if it is a drug and it bears or contains, for purposes of coloring only, a coal-tar color other than one from a batch that has been certified in accordance with regulations as provided by section 504.

(b) If it purports to be or is represented as a drug the name of which is recognized in an official compendium, and its strength differs from, or its quality or purity falls below, the standard set forth in such compendium. Such determination as to strength, quality, or purity shall be made in accordance with the tests or methods of assay set forth in such compendium, except that whenever tests or methods of assay have not been prescribed in such compendium, or such tests or methods of assay as are prescribed are, in the judgment of the Secretary, insufficient for the making of such determination, the Secretary shall bring such fact to the attention of the appropriate body charged with the revision of such compendium, and if such body fails within a reasonable time to prescribe test or methods of assay which, in the judgment of the Secretary, are sufficient for purposes of this paragraph, then the Secretary shall promulgate regulations prescribing appropriate tests or methods of assay in accordance with which such determination as to strength, quality, or purity shall be made. No drug defined in an official compendium shall be deemed to be adulterated under this paragraph because it differs from the standard of strength, quality, or purity therefor set forth in such compendium, if its difference in strength, quality, or purity from such standards is plainly stated on its label. Whenever a drug is recognized in both the United States Pharmacopoeia and the Homoeopathic Pharmacopoeia of the United States it shall be subject to the requirements of the United States Pharmacopoeia unless it is labeled and offered for sale as a homoeopathic drug, in which case it shall be subject to the provisions of the Homoeopathic Pharmacopoeia of the United States and not to those of the United States Pharmacopoeia.

[SEC. 501. A drug or device shall be deemed to be adulterated—]

(c) If it is not subject to the provisions of paragraph (b) of this section and its strength differs from, or its purity or quality falls below, that which it purports or is represented to possess.

(d) If it is a drug and any substance has been (1) mixed or packed therewith so as to reduce its quality or strength or (2) substituted wholly or in part therefor.

Misbranded Drugs and Devices

SEC. 502. A drug or device shall be deemed to be misbranded— (a) If its labeling is false or misleading in any particular.

(b) If in a package form unless it bears a label containing (1) the name and place of business of the manufacturer, packer, or distributor; and (2) an accurate state-

ment of the quantity of the contents in terms of weight, measure, or numerical count: *Provided*, That under clause (2) of this paragraph reasonable variations shall be permitted, and exemptions as to small packages shall be established, by regulations prescribed by the Secretary.

(c) If any word, statement, or other information required by or under authority of this Act to appear on the label or labeling is not prominently placed thereon with such conspicuousness (as compared with other words, statements, designs, or devices, in the labeling) and in such terms as to render it likely to be read and understood by the ordinary individual under customary conditions of purchase and use.

(d) If it is for use by man and contains any quantity of the narcotic or hypnotic substance alpha-eucaine, barbituric acid, beta-eucaine, bromal, cannabis, carbromal, chloral, coca, cocaine, codeine, heroin, marihuana, morphine, opium, paraldehyde, peyote, or sulfonmethane; or any chemical derivative of such substance, which derivative has been by the Secretary, after investigation, found to be, and by regulations⁵ designated as, habit forming; unless its label bears the name, and quantity or proportion of such substance or derivative and in juxtaposition therewith the statement "Warning—May be habit forming."

(e) If it is a drug and is not designated solely by a name recognized in an official compendium unless its label bears (1) the common or usual name of the drug, if such there be; and (2), in case it is fabricated from two or more ingredients, the common or usual name of each active ingredient, including the quantity, kind, and proportion of any alcohol, and also including whether active or not, the name and quantity or proportion of any bromides, ether, chloroform, acetanilid, acetphenetidin, amidopyrine, antipyrine, atropine, hyoscyne, hyoscyamine, arsenic, digitalis, digitalis glucosides, mercury, ouabain, strophanthin, strychnine, thyroid, or any derivative or preparation of any such substances, contained therein: *Provided*, That to the extent that compliance with the requirements of clause (2) of this paragraph is impracticable, exemptions shall be established by regulations promulgated by the Secretary.

(f) Unless its labeling bears (1) adequate directions for use; and (2) such adequate warnings against use in those pathological conditions or by children where its use may be dangerous to health, or against unsafe dosage or methods or duration of administration or application, in such manner and form, as are necessary for the protection of users: *Provided*, That where any requirement of clause (1) of this paragraph, as applied to any drug or device, is not necessary for the protection of the public health, the Secretary shall promulgate regulations exempting such drug or device from such requirement.

(g) If it purports to be a drug the name of which is recognized in an official compendium, unless it is packaged and labeled as prescribed therein: *Provided*, That the method of packing may be modified with the consent of the Secretary. Whenever a drug is recognized in both the United States Pharmacopoeia and the Homoeopathic Pharmacopoeia of the United States, it shall be subject to the requirements of the United States Pharmacopoeia with respect to packaging and labeling unless it is labeled and offered for sale as a homoeopathic drug, in which case it shall be subject to the provisions of the Homoeopathic Pharmacopoeia of the United States, and not to those of the United States Pharmacopoeia.

(h) If it has been found by the Secretary to be a drug liable to deterioration, unless it is packaged in such form and manner, and its label bears a statement of such precautions, as the Secretary shall by regulations require as necessary for the protection of the public health. No such regulation shall be established for any drug recognized

⁵ 21 CFR 145.1.

in an official compendium until the Secretary shall have informed the appropriate body charged with the revision of such compendium of the need for such packaging or labeling requirements and such body shall have failed within a reasonable time to prescribe such requirements.

(i) (1) If it is a drug and its container is so made, formed, or filled as to be misleading; or (2) if it is an imitation of another drug; or (3) if it is offered for sale under the name of another drug.

(j) If it is dangerous to health when used in the dosage, or with the frequency or duration prescribed, recommended, or suggested in the labeling thereof.

(k) If it is, or purports to be, or is represented as a drug composed wholly or partly of insulin, unless (1) it is from a batch with respect to which a certificate or release has been issued pursuant to section 506, and (2) such certificate or release is in effect with respect to such drug.

(l) If it is, or purports to be, or is represented as a drug composed wholly or partly of any kind of penicillin, streptomycin, aureomycin, chloramphenicol, or bacitracin, or any derivative thereof, unless (1) it is from a batch with respect to which a certificate or release has been issued pursuant to section 507, and (2) such certificate or release is in effect with respect to such drug: *Provided*, That this paragraph shall not apply to any drug or class of drugs exempted by regulations promulgated under section 507 (c) or (d).

Exemptions in Case of Drugs and Devices

SEC. 503. (a) The Secretary is hereby directed to promulgate regulations exempting from any labeling or packaging requirement of this Act drugs and devices which are, in accordance with the practice of the trade, to be processed, labeled, or repacked in substantial quantities at establishments other than those where originally processed or packed, on condition that such drugs and devices are not adulterated or misbranded, under the provisions of this Act upon removal from such processing, labeling, or repacking establishment.

[SEC. 503] (b) (1) A drug intended for use by man which—

(A) is a habit-forming drug to which section 502 (d) applies; or

(B) because of its toxicity or other potentiality for harmful effect, or the method of its use, or the collateral measures necessary to its use, is not safe for use except under the supervision of a practitioner licensed by law to administer such drug; or

(C) is limited by an effective application under section 505 to use under the professional supervision of a practitioner licensed by law to administer such drug, shall be dispensed only (i) upon a written prescription of a practitioner licensed by law to administer such drug, or (ii) upon an oral prescription of such practitioner which is reduced promptly to writing and filed by the pharmacist, or (iii) by refilling any such written or oral prescription if such refilling is authorized by the prescriber either in the original prescription or by oral order which is reduced promptly to writing and filed by the pharmacist. The act of dispensing a drug contrary to the provisions of this paragraph shall be deemed to be an act which results in the drug being misbranded while held for sale.

(2) Any drug dispensed by filling or refilling a written or oral prescription of a practitioner licensed by law to administer such drug shall be exempt from the requirements of section 502, except paragraphs (a), (i) (2) and (3), (k), and (l), and the packaging requirements of paragraphs (g) and (h), if the drug bears a label containing the name and address of the dispenser, the serial number and date of the prescription or of its filling, the name of the prescriber, and if stated in the prescription, the name

of the patient, and the directions for use and cautionary statements, if any, contained in such prescription. This exemption shall not apply to any drug dispensed in the course of the conduct of a business of dispensing drugs pursuant to diagnosis by mail, or to a drug dispensed in violation of paragraph (1) of this subsection.

(3) The Secretary may by regulation remove drugs subject to section 502 (d) and section 505 from the requirements of paragraph (1) of this subsection when such requirements are not necessary for the protection of the public health.

(4) A drug which is subject to paragraph (1) of this subsection shall be deemed to be misbranded if at any time prior to dispensing its label fails to bear the statement "Caution: Federal law prohibits dispensing without prescription." A drug to which paragraph (1) of this subsection does not apply shall be deemed to be misbranded if at any time prior to dispensing its label bears the caution statement quoted in the preceding sentence.

(5) Nothing in this subsection shall be construed to relieve any person from any requirement prescribed by or under authority of law with respect to drugs now included or which may hereafter be included within the classifications stated in section 3220 of the Internal Revenue Code (26 U. S. C. 3220), or to marihuana as defined in section 3238 (b) of the Internal Revenue Code (26 U. S. C. 3238 (b)).

Certification of Coal-Tar Colors for Drugs

SEC. 504. The Secretary shall promulgate regulations⁴ providing for the listing of coal-tar colors which are harmless and suitable for use in drugs for purposes of coloring only and for the certification of batches of such colors, with or without harmless diluents.

New Drugs

SEC. 505. (a) No person shall introduce or deliver for introduction into interstate commerce any new drug,⁶ unless an application filed pursuant to subsection (b) is effective with respect to such drug.

[SEC. 505] (b) Any person may file with the Secretary an application with respect to any drug subject to the provisions of subsection (a). Such persons shall submit to the Secretary as a part of the application (1) full reports of investigations which have been made to show whether or not such drug is safe for use; (2) a full list of the articles used as components of such drug; (3) a full statement of the composition of such drug; (4) a full description of the methods used in, and the facilities and controls used for, the manufacture, processing, and packing of such drug; (5) such samples of such drug and of the articles used as components thereof as the Secretary may require; and (6) specimens of the labeling proposed to be used for such drug.

[SEC. 505] (c) An application provided for in subsection (b) shall become effective on the sixtieth day after the filing thereof unless prior to such day the Secretary by notice to the applicant in writing postpones the effective date of the application to such time (not more than one hundred and eighty days after the filing thereof) as the Secretary deems necessary to enable him to study and investigate the application.

[SEC. 505] (d) If the Secretary finds, after due notice to the applicant and giving him an opportunity for a hearing, that (1) the investigations, reports of which are required to be submitted to the Secretary pursuant to subsection (b), do not include adequate tests by all methods reasonably applicable to show whether or not such drug is safe for use under the conditions prescribed, recommended, or suggested in

⁴ 21 CFR 135.1 *eq. seq.*; Service and Regulatory Announcements, Food, Drug, and Cosmetic No. 3.

⁶ Definition of the term "new drug" appears on page 882.

the proposed labeling thereof; (2) the results of such tests show that such drug is unsafe for use under such conditions or do not show that such drug is safe for use under such conditions; (3) the methods used in, and the facilities and controls used for, the manufacture, processing, and packing of such drug are inadequate to preserve its identity, strength, quality, and purity; or (4) upon the basis of the information submitted to him as part of the application, or upon the basis of any other information before him with respect to such drug, he has insufficient information to determine whether such drug is safe for use under such conditions, he shall, prior to the effective date of the application, issue an order refusing to permit the application to become effective.

[SEC. 505] (e) The effectiveness of an application with respect to any drug shall, after due notice and opportunity for hearing to the applicant, by order of the Secretary be suspended if the Secretary finds (1) that clinical experience, tests by new methods, or tests by methods not deemed reasonably applicable when such application became effective show that such drug is unsafe for use under the conditions of use upon the basis of which the application became effective, or (2) that the application contains any untrue statement of a material fact. The order shall state the findings upon which it is based.

[SEC. 505] (f) An order refusing to permit an application with respect to any drug to become effective shall be revoked whenever the Secretary finds that the facts so require.

(g) Orders of the Secretary issued under this section shall be served (1) in person by any officer or employee of the Department designated by the Secretary or (2) by mailing the order by registered mail addressed to the applicant or respondent at his last-known address in the records of the Secretary.

(h) An appeal may be taken by the applicant from an order of the Secretary refusing to permit the application to become effective, or suspending the effectiveness of the application. Such appeal shall be taken by filing in the district court of the United States within any district wherein such applicant resides or has his principal place of business, or in the District Court of the United States for the District of Columbia, within sixty days after the entry of such order, a written petition praying that the order of the Secretary be set aside. A copy of such petition shall be forthwith served upon the Secretary, or upon any officer designated by him for that purpose, and thereupon the Secretary shall certify and file in the court a transcript of the record upon which the order complained of was entered. Upon the filing of such transcript such court shall have exclusive jurisdiction to affirm or set aside such order. No objection to the order of the Secretary shall be considered by the court unless such objection shall have been urged before the Secretary or unless there were reasonable grounds for failure so to do. The finding of the Secretary as to the facts, if supported by substantial evidence, shall be conclusive. If any person shall apply to the court for leave to adduce additional evidence, and shall show to the satisfaction of the court that such additional evidence is material and that there were reasonable grounds for failure to adduce such evidence in the proceeding before the Secretary, the court may order such additional evidence to be taken before the Secretary and to be adduced upon the hearing in such manner and upon such terms and conditions as to the court may seem proper. The Secretary may modify his findings as to the facts by reason of the additional evidence so taken, and he shall file with the court such modified findings which, if supported by substantial evidence, shall be conclusive, and his recommendation, if any, for the setting aside of the original order. The judgment and decree of the court affirming or setting aside any such order of the Secretary shall be final, subject to review as provided in sections 128, 239, and 240 of the Judicial Code, as amended [now covered by U. S. C., title 28, secs. 1291-1294,

1254], and in section 7, as amended, of the Act entitled "An Act to establish a Court of Appeals for the District of Columbia," approved February 9, 1893 [now covered by U. S. C., title 28, secs. 1291, 1292]. The commencement of proceedings under this subsection shall not, unless specifically ordered by the court to the contrary, operate as a stay of the Secretary's order.

(i) The Secretary shall promulgate regulations for exempting from the operation of this section drugs intended solely for investigational use by experts qualified by scientific training and experience to investigate the safety of drugs.

Certification of Drugs Containing Insulin

SEC. 506. (a) The Secretary of Health, Education, and Welfare, pursuant to regulations⁷ promulgated by him, shall provide for the certification of batches of drugs composed wholly or partly of insulin. A batch of any such drug shall be certified if such drug has such characteristics of identity and such batch has such characteristics of strength, quality, and purity, as the Secretary prescribes in such regulations as necessary to adequately insure safety and efficacy of use, but shall not otherwise be certified. Prior to the effective date of such regulations the Secretary, in lieu of certification, shall issue a release for any batch which, in his judgment, may be released without risk as to the safety and efficacy of its use. Such release shall prescribe the date of its expiration and other conditions under which it shall cease to be effective as to such batch and as to portions thereof.

(b) Regulations providing for such certification shall contain such provisions as are necessary to carry out the purposes of this section, including provisions prescribing (1) standards of identity and of strength, quality, and purity; (2) tests and methods of assay to determine compliance with such standards; (3) effective periods for certificates, and other conditions under which they shall cease to be effective as to certified batches and as to portions thereof; (4) administration and procedure; and (5) such fees, specified in such regulations, as are necessary to provide, equip, and maintain an adequate certification service. Such regulations shall prescribe no standard of identity or of strength, quality, or purity for any drug different from the standard of identity, strength, quality, or purity set forth for such drug in an official compendium.

(c) Such regulations, insofar as they prescribe tests or methods of assay to determine strength, quality, or purity of any drug, different from the tests or methods of assay set forth for such drug in an official compendium, shall be prescribed, after notice and opportunity for revision of such compendium, in the manner provided in the second sentence of section 501 (b). The provisions of subsections (e), (f), and (g) of section 701 shall be applicable to such portion of any regulation as prescribes any such different test or method, but shall not be applicable to any other portion of any such regulation.

Certification of Drugs Containing Penicillin, Streptomycin, Chlortetracycline, Chloramphenicol, or Bacitracin

SEC. 507. (a) The Secretary of Health, Education, and Welfare, pursuant to regulations⁹ promulgated by him, shall provide for the certification of batches of drugs composed wholly or partly of any kind of penicillin, streptomycin, chlortetracycline,

⁷ 21 CFR 144.1 *et seq.*

⁹ 21 CFR 141.1 *et seq.*, 146.1 *et seq.* Compilation of Regulations for Tests and Methods of Assay and Certification of Antibiotic Drugs: Vol. 1, Tests and Methods of Assay; Vol. 2, Certification of Antibiotic Drugs.

chloramphenicol, or bacitracin or any derivative thereof. A batch of any such drug shall be certified if such drug has such characteristics of identity and such batch has such characteristics of strength, quality, and purity, as the Secretary prescribes in such regulations as necessary to adequately insure safety and efficacy of use, but shall not otherwise be certified. Prior to the effective date of such regulations the Secretary, in lieu of certification, shall issue a release for any batch which, in his judgment, may be released without risk as to the safety and efficacy of its use. Such release shall prescribe the date of its expiration and other conditions under which it shall cease to be effective as to such batch and as to portions thereof.

(b) Regulations providing for such certifications shall contain such provisions as are necessary to carry out the purposes of this section, including provisions prescribing (1) standards of identity and of strength, quality, and purity; (2) tests and methods of assay to determine compliance with such standards; (3) effective periods for certificates, and other conditions under which they shall cease to be effective as to certified batches and as to portions thereof; (4) administration and procedure; and (5) such fees, specified in such regulations, as are necessary to provide, equip, and maintain an adequate certification service. Such regulations shall prescribe only such tests and methods of assay as will provide for certification or rejection within the shortest time consistent with the purposes of this section.

(c) Whenever in the judgment of the Secretary, the requirements of this section and of section 502 (1) with respect to any drug or class of drugs are not necessary to insure safety and efficacy of use, the Secretary shall promulgate regulations exempting such drug or class of drugs from such requirements.

(d) The Secretary shall promulgate regulations exempting from any requirement of this section and of section 502 (1), (1) drugs which are to be stored, processed, labeled, or repacked at establishments other than those where manufactured, on condition that such drugs comply with all such requirements upon removal from such establishments; (2) drugs which conform to applicable standards of identity, strength, quality, and purity prescribed by these regulations and are intended for use in manufacturing other drugs; and (3) drugs which are intended solely for investigational use by experts qualified by scientific training and experience to investigate the safety and efficacy of drugs.

(e) No drug which is subject to section 507 shall be deemed to be subject to any provision of section 505. Compliance of any drug subject to section 502 (1) or 507 with sections 501 (b) and 502 (g) shall be determined by the application of the standards of strength, quality, and purity, the tests and methods of assay, and the requirements of packaging and labeling, respectively, prescribed by regulations promulgated under section 507.

(f) Any interested person may file with the Secretary a petition proposing the issuance, amendment, or repeal of any regulation contemplated by this section. The petition shall set forth the proposal in general terms and shall state reasonable grounds therefor. The Secretary shall give public notice of the proposal and an opportunity for all interested persons to present their views thereon, orally or in writing, and as soon as practicable thereafter shall make public his action upon such proposal. At any time prior to the thirtieth day after such action is made public any interested person may file objections to such action, specifying with particularity the changes desired, stating reasonable grounds therefor, and requesting a public hearing upon such objections. The Secretary shall thereupon, after due notice, hold such public hearing. As soon as practicable after completion of the hearing, the Secretary shall by order make public his action on such objections. The Secretary shall base his order only on substantial evidence of record at the hearing and shall set

forth as part of the order detailed findings of fact on which the order is based. The order shall be subject to the provisions of section 701 (f) and (g).

CHAPTER VI—COSMETICS

Adulterated Cosmetics

SEC. 601. A cosmetic shall be deemed to be adulterated—

(a) If it bears or contains any poisonous or deleterious substance which may render it injurious to users under the conditions of use prescribed in the labeling thereof, or under such conditions of use as are customary or usual: *Provided*, That this provision shall not apply to coal-tar hair dye, the label of which bears the following legend conspicuously displayed thereon: "Caution—This product contains ingredients which may cause skin irritation on certain individuals and a preliminary test according to accompanying directions should first be made. This product must not be used for dyeing the eyelashes or eyebrows; to do so may cause blindness.", and the labeling of which bears adequate directions for such preliminary testing. For the purposes of this paragraph and paragraph (e) the term "hair dye" shall not include eyelash dyes or eyebrow dyes.

(b) If it consists in whole or in part of any filthy, putrid, or decomposed substance.

(c) If it has been prepared, packed, or held under insanitary conditions whereby it may have been rendered injurious to health.

(d) If its container is composed, in whole or in part, of any poisonous or deleterious substance which may render the contents injurious to health.

(e) If it is not a hair dye and it bears or contains a coal-tar color other than one from a batch that has been certified in accordance with regulations as provided by section 604.

Misbranded Cosmetics

SEC. 602. A cosmetic shall be deemed to be misbranded—

(a) If its labeling is false or misleading in any particular.

(b) If in package form unless it bears a label containing (1) the name and place of business of the manufacturer, packer, or distributor; and (2) an accurate statement of the quantity of the contents in terms of weight, measure, or numerical count: *Provided*, That under clause (2) of this paragraph reasonable variations shall be permitted, and exemptions as to small packages shall be established, by regulations prescribed by the Secretary.

(c) If any word, statement, or other information required by or under authority of this Act to appear on the label or labeling is not prominently placed thereon with such conspicuousness (as compared with other words, statements, designs, or devices, in the labeling) and in such terms as to render it likely to be read and understood by the ordinary individual under customary conditions of purchase and use.

(d) If its container is so made, formed, or filled as to be misleading.

Regulations Making Exemptions

SEC. 603. The Secretary shall promulgate regulations exempting from any labeling requirement of this Act cosmetics which are, in accordance with the practice of the trade, to be processed, labeled, or repacked in substantial quantities at establishments other than those where originally processed or packed, on condition that such cosmetics are not adulterated or misbranded under the provisions of this Act upon removal from such processing, labeling, or repacking establishment.

Certification of Coal-Tar Colors for Cosmetics

SEC. 604. The Secretary shall promulgate regulations⁴ providing for the listing of coal-tar colors which are harmless and suitable for use in cosmetics and for the certification of batches of such colors, with or without harmless diluents.

CHAPTER VII—GENERAL ADMINISTRATIVE PROVISIONS

Regulations and Hearings

SEC. 701. (a) The authority to promulgate regulations for the efficient enforcement of this Act, except as otherwise provided in this section, is hereby vested in the Secretary.

(b) The Secretary of the Treasury and the Secretary of Health, Education, and Welfare shall jointly prescribe regulations for the efficient enforcement of the provisions of section 801, except as otherwise provided therein. Such regulations shall be promulgated in such manner and take effect at such time, after due notice, as the Secretary of Health, Education, and Welfare shall determine.

(c) Hearings authorized or required by this Act shall be conducted by the Secretary or such officer or employee as he may designate for the purpose.

(d) The definitions and standards of identity promulgated in accordance with the provisions of this Act shall be effective for the purposes of the enforcement of this Act, notwithstanding such definitions and standards as may be contained in other laws of the United States and regulations promulgated thereunder.

(e) The Secretary, on his own initiative or upon an application of any interested industry or substantial portion thereof stating reasonable grounds therefor, shall hold a public hearing¹⁰ upon a proposal to issue, amend, or repeal any regulation contemplated by any of the following sections of this Act: 403 (j), 404 (a), 406 (a) and (b), 501 (b), 502 (d), 502 (h), 504, and 604. The Secretary shall give appropriate notice of the hearing, and the notice shall set forth the proposal in general terms and specify the time and place for a public hearing to be held thereon not less than thirty days after the date of the notice, except that the public hearing on regulations under section 404 (a) may be held within a reasonable time, to be fixed by the Secretary, after notice thereof. At the hearing any interested person may be heard in person or by his representative. As soon as practicable after completion of the hearing, the Secretary shall by order make public his action in issuing, amending, or repealing the regulation or determining not to take such action. The Secretary shall base his order only on substantial evidence of record at the hearing and shall set forth as part of the order detailed findings of fact on which the order is based. No such order shall take effect prior to the ninetieth day after it is issued, except that if the Secretary finds that emergency conditions exist necessitating an earlier effective date, then the Secretary shall specify in the order his findings as to such conditions and the order shall take effect at such earlier date as the Secretary shall specify therein to meet the emergency.

(f) (1) In a case of actual controversy as to the validity of any order under subsection (e), any person who will be adversely affected by such order if placed in effect may at any time prior to the nintieth day after such order is issued file a petition with the Circuit Court of Appeals of the United States for the circuit wherein such person resides or has his principal place of business, for a judicial review of such order.

⁴ 21 CFR 135.1 *et seq.*; Service and Regulatory Announcements, Food, Drug, and Cosmetic No. 3.

¹⁰ 21 CFR 1.701 *et seq.*

The summons and petition may be served at any place in the United States. The Secretary, promptly upon service of the summons and petition, shall certify and file in the court the transcript of the proceedings and the record on which the Secretary based his order.

(2) If the petitioner applies to the court for leave to adduce additional evidence, and shows to the satisfaction of the court that such additional evidence is material and that there were reasonable grounds for the failure to adduce such evidence in the proceeding before the Secretary, the court may order such additional evidence (and evidence in rebuttal thereof) to be taken before the Secretary, and to be adduced upon the hearing, in such manner and upon such terms and conditions as to the court may seem proper. The Secretary may modify his findings as to the facts, or make new findings, by reason of the additional evidence so taken, and he shall file such modified or new findings, and his recommendation, if any, for the modification or setting aside of his original order, with the return of such additional evidence.

(3) The court shall have jurisdiction to affirm the order, or to set it aside in whole or in part, temporarily or permanently. If the order of the Secretary refuses to issue, amend, or repeal a regulation and such order is not in accordance with law the court shall by its judgment order the Secretary to take action, with respect to such regulation, in accordance with law. The findings of the Secretary as to the facts, if supported by substantial evidence, shall be conclusive.

(4) The judgment of the court affirming or setting aside, in whole or in part, any such order of the Secretary shall be final, subject to review by the Supreme Court of the United States upon certiorari or certification as provided in sections 239 and 240 of the Judicial Code, as amended.

(5) Any action instituted under this subsection shall survive notwithstanding any change in the person occupying the office of Secretary or any vacancy in such office.

(6) The remedies provided for in this subsection shall be in addition to and not in substitution for any other remedies provided by law.

(g) A certified copy of the transcript of the record and proceedings under subsection (e) shall be furnished by the Secretary to any interested party at his request, and payment of the costs thereof, and shall be admissible in any criminal, libel for condemnation, exclusion of imports, or other proceeding arising under or in respect to this Act, irrespective of whether proceedings with respect to the order have previously been instituted or become final under subsection (f).

Examinations and Investigations

SEC. 702. (a) The Secretary is authorized to conduct examinations and investigations for the purposes of this Act through officers and employees of the Department or through any health, food, or drug officer or employee of any State, Territory, or political subdivision thereof, duly commissioned by the Secretary as an officer of the Department. In the case of food packed in a Territory the Secretary shall attempt to make inspection of such food at the first point of entry within the United States when, in his opinion and with due regard to the enforcement of all the provisions of this Act, the facilities at his disposal will permit of such inspection. For the purposes of this subsection the term "United States" means the States and the District of Columbia.

(b) Where a sample of a food, drug, or cosmetic is collected for analysis under this Act the Secretary shall, upon request, provide a part of such official sample for examination or analysis by any person named on the label of the article, or the owner thereof, or his attorney or agent; except that the Secretary is authorized, by regulations, to make such reasonable exceptions from, and impose such reasonable terms

and conditions relating to, the operation of this subsection as he finds necessary for the proper administration of the provisions of this Act.

[SEC. 702] (c) For purposes of enforcement of this Act, records of any department or independent establishment in the executive branch of the Government shall be open to inspection by any official of the Department of Health, Education, and Welfare duly authorized by the Secretary to make such inspection.

Sea-food Inspection

SEC. 702a.¹¹ The Secretary of Health, Education, and Welfare, upon application of any packer of any sea food for shipment or sale within the jurisdiction of this Act, may, at his discretion, designate inspectors to examine and inspect such food and the production, packing, and labeling thereof. If on such examination and inspection compliance is found with the provisions of this Act and regulations¹² promulgated thereunder, the applicant shall be authorized or required to mark the food as provided by regulation to show such compliance. Services under this section shall be rendered only upon payment by the applicant of fees fixed by regulation in such amounts as may be necessary to provide, equip, and maintain an adequate and efficient inspection service. Receipts from such fees shall be covered into the Treasury and shall be available to the Secretary of Health, Education, and Welfare for expenditures incurred in carrying out the purposes of this section, including expenditures for salaries of additional inspectors when necessary to supplement the number of inspectors for whose salaries Congress has appropriated. The Secretary is hereby authorized to promulgate regulations governing the sanitary and other conditions under which the service herein provided shall be granted and maintained and for otherwise carrying out the purposes of this section. Any person who forges, counterfeits, simulates, or falsely represents, or without proper authority uses any mark, stamp, tag, label, or other identification devices authorized or required by the provisions of this section or regulations thereunder, shall be guilty of a misdemeanor, and shall on conviction thereof be subject to imprisonment for not more than one year or a fine of not less than \$1,000 nor more than \$5,000 or both such imprisonment and fine.

Records of Interstate Shipment

SEC. 703. For the purpose of enforcing the provisions of this Act, carriers engaged in interstate commerce, and persons receiving food, drugs, devices, or cosmetics in interstate commerce or holding such articles so received, shall, upon the request of an officer or employee duly designated by the Secretary, permit such officer or employee, at reasonable times, to have access to and to copy all records showing the movement in interstate commerce of any food, drug, device, or cosmetic, or the holding thereof during or after such movement, and the quantity, shipper, and consignee thereof; and it shall be unlawful for any such carrier or person to fail to permit such access to and copying of any such record so requested when such request is accompanied by a statement in writing specifying the nature or kind of food, drug, device, or cosmetic to which such request relates: *Provided*, That evidence obtained under this section

¹¹ Sec. 902 (a) provides that the amendment to the Food and Drugs Act, section 10A, shall remain in force and effect and be applicable to the provisions of this Act. The Labor-Federal Security Appropriation Act of July 12, 1943 (ch. 221, title II, § 1, 57 Stat. 500) renumbered this section as 702A of the Federal Food, Drug, and Cosmetic Act. Title 21 U. S. C., 1946 ed., codifies this section as 372 a.

¹² 21 CFR 155.1 *et seq.*

shall not be used in a criminal prosecution of the person from whom obtained: *Provided further*, That carriers shall not be subject to the other provisions of this Act by reason of their receipt, carriage, holding, or delivery of food, drugs, devices, or cosmetics in the usual course of business as carriers.

Factory Inspection

"SEC. 704. (a) For purposes of enforcement of this Act, officers or employees duly designated by the Secretary, upon presenting appropriate credentials and a written notice to the owner, operator, or agent in charge, are authorized (1) to enter, at reasonable times, any factory, warehouse, or establishment in which food, drugs, devices, or cosmetics are manufactured, processed, packed, or held, for introduction into interstate commerce or are held after such introduction, or to enter any vehicle being used to transport or hold such food, drugs, devices, or cosmetics in interstate commerce; and (2) to inspect, at reasonable times and within reasonable limits and in a reasonable manner, such factory, warehouse, establishment, or vehicle and all pertinent equipment, finished and unfinished materials, containers, and labeling therein. A separate notice shall be given for each such inspection, but a notice shall not be required for each entry made during the period covered by the inspection. Each such inspection shall be commenced and completed with reasonable promptness.

"(b) Upon completion of any such inspection of a factory, warehouse, or other establishment, and prior to leaving the premises, the officer or employee making the inspection shall give to the owner, operator, or agent in charge a report in writing setting forth any conditions or practices observed by him which, in his judgment, indicate that any food, drug, device, or cosmetic in such establishment (1) consists in whole or in part of any filthy, putrid, or decomposed substance, or (2) has been prepared, packed, or held under insanitary conditions whereby it may have become contaminated with filth, or whereby it may have been rendered injurious to health. A copy of such report shall be sent promptly to the Secretary.

"(c) If the officer or employee making any such inspection of a factory, warehouse, or other establishment has obtained any sample in the course of the inspection, upon completion of the inspection and prior to leaving the premises he shall give to the owner, operator, or agent in charge a receipt describing the samples obtained.

"(d) Whenever in the course of any such inspection of a factory or other establishment where food is manufactured, processed, or packed, the officer or employee making the inspection obtains a sample of any such food, and an analysis is made of such sample for the purpose of ascertaining whether such food consists in whole or in part of any filthy, putrid, or decomposed substance, or is otherwise unfit for food, a copy of the results of such analysis shall be furnished promptly to the owner, operator, or agent in charge."

Publicity

SEC. 705. (a) The Secretary shall cause to be published from time to time reports summarizing all judgments, decrees, and court orders which have been rendered under this Act, including the nature of the charge and the disposition thereof.

(b) The Secretary may also cause to be disseminated information regarding food, drugs, devices, or cosmetics in situations involving, in the opinion of the Secretary, imminent danger to health, or gross deception of the consumer. Nothing in this section shall be construed to prohibit the Secretary from collecting, reporting, and illustrating the results of the investigations of the Department.

Cost of Certification of Coal-tar Colors

SEC. 706. The admitting to listing and certification of coal-tar colors, in accordance with regulations⁴ prescribed under this Act, shall be performed only upon payment of such fees, which shall be specified in such regulations, as may be necessary to provide, maintain, and equip an adequate service for such purposes.

CHAPTER VIII—IMPORTS AND EXPORTS

SEC. 801 (a) The Secretary of the Treasury shall deliver to the Secretary of Health, Education, and Welfare, upon his request, samples of food, drugs, devices, and cosmetics which are being imported or offered for import into the United States, giving notice thereof to the owner or consignee, who may appear before the Secretary of Health, Education, and Welfare and have the right to introduce testimony. If it appears from the examination of such samples or otherwise that (1) such article has been manufactured, processed, or packed under insanitary conditions, or (2) such article is forbidden or restricted in sale in the country in which it was produced or from which it was exported, or (3) such article is adulterated, misbranded, or in violation of section 505, then such article shall be refused admission, except as provided in subsection (b) of this section. The Secretary of the Treasury shall cause the destruction of any such article refused admission unless such article is exported, under regulations prescribed by the Secretary of the Treasury, within ninety days of the date of notice of such refusal or within such additional time as may be permitted pursuant to such regulations. This paragraph shall not be construed to prohibit the admission of narcotic drugs the importation of which is permitted under section 2 of the Act of May 26, 1922, as amended (U. S. C., 1946 edition, title 21, sec. 173).

(b) Pending decision as to the admission of an article being imported or offered for import, the Secretary of the Treasury may authorize delivery of such article to the owner or consignee upon the execution by him of a good and sufficient bond providing for the payment of such liquidated damages in the event of default as may be required pursuant to regulations of the Secretary of the Treasury. If it appears to the Secretary of Health, Education, and Welfare that an article included within the provisions of clause (3) of subsection (a) of this section can, by relabeling or other action, be brought into compliance with the Act or rendered other than a food, drug, device, or cosmetic, final determination as to admission of such article may be deferred and, upon filing of timely written application by the owner or consignee and the execution by him of a bond as provided in the preceding provisions of this subsection, the Secretary may, in accordance with regulations, authorize the applicant to perform such relabeling or other action specified in such authorization (including destruction or export of rejected articles or portions thereof, as may be specified in the Secretary's authorization). All such relabeling or other action pursuant to such authorization shall in accordance with regulations be under the supervision of an officer or employee of the Department of Health, Education, and Welfare designated by the Secretary, or an officer or employee of the Department of the Treasury designated by the Secretary of the Treasury.

(c) All expenses (including travel, per diem or subsistence, and salaries of officers or employees of the United States) in connection with the destruction provided for in subsection (a) of this section and the supervision of the relabeling or other action

⁴ 21 CFR 135.1 *et seq.*; Service and Regulatory Announcements, Food, Drug, and Cosmetic No. 3.

authorized under the provisions of subsection (b) of this section, the amount of such expenses to be determined in accordance with regulations, and all expenses in connection with the storage, cartage, or labor with respect to any article refused admission under subsection (a) of this section, shall be paid by the owner or consignee and, in default of such payment, shall constitute a lien against any future importations made by such owner or consignee.

[SEC. 801] (d) A food, drug, device, or cosmetic intended for export shall not be deemed to be adulterated or misbranded under this Act if it (1) accords to the specifications of the foreign purchaser, (2) is not in conflict with the laws of the country to which it is intended for export, and (3) is labeled on the outside of the shipping package to show that it is intended for export. But if such article is sold or offered for sale in domestic commerce, this subsection shall not exempt it from any of the provisions of this Act.

CHAPTER IX—MISCELLANEOUS

Separability Clause

SEC. 901. If any provision of this Act is declared unconstitutional, or the applicability thereof to any person or circumstances is held invalid, the constitutionality of the remainder of the Act and the applicability thereof to other persons and circumstances shall not be affected thereby.

Effective Date and Repeals

SEC. 902. (a) This Act shall take effect twelve months after the date of its enactment.¹⁴ The Federal Food and Drugs Act of June 30, 1906, as amended (U. S. C., 1934 ed., title 21, secs. 1-15), shall remain in force until such effective date, and, except as otherwise provided in this subsection, is hereby repealed effective upon such date: *Provided*, That the provisions of section 701 shall become effective on the enactment of this Act, and thereafter the Secretary [of Agriculture] is authorized hereby to (1) conduct hearings and to promulgate regulations which shall become effective on or after the effective date of this Act as the Secretary [of Agriculture] shall direct, and (2) designate prior to the effective date of this Act food having common or usual names and exempt such food from the requirements of clause (2) of section 403 (i) for a reasonable time to permit the formulation, promulgation, and effective application of definitions and standards of identity therefor as provided by section 401: *Provided further*, That sections 502 (j), 505, and 601 (a), and all other provisions of this Act to the extent that they may relate to the enforcement of such sections, shall take effect on the date of the enactment of this Act, except that in the case of a cosmetic to which the proviso of section 601 (a) relates, such cosmetic shall not, prior to the ninetieth day after such date of enactment, be deemed adulterated by reason of the failure of its label to bear the legend prescribed in such proviso: *Provided further*, That the Act of March 4, 1923¹⁵ (U. S. C., 1946 ed., title 21, sec. 321a; 42 Stat. 1500, ch. 268), defining butter and providing a standard therefor; the Act of July 24, 1919¹⁶ (U. S. C., 1946 ed., title 21, sec. 321b; 41 Stat. 271, ch. 26), defining wrapped meats as in package form; and the amendment to the Food and Drugs Act, section 10A, ap-

¹⁴ The Act of June 23, 1939, temporarily postponed the operation of certain provisions until January 1, 1940, and July 1, 1940.

¹⁵ See page 882 for definition of "butter."

¹⁶ See page 883 for definition of "package."

proved August 27, 1935¹⁷ (U. S. C., 1946 ed., title 21, sec. 372a [49 Stat. 871, ch. 739]), shall remain in force and effect and be applicable to the provisions of this Act.

(b) Meats and meat food products shall be exempt from the provisions of this Act to the extent of the application or the extension thereto of the Meat Inspection Act, approved March 4, 1907, as amended (U. S. C., 1946 ed., title 21, secs. 71-96; 34 Stat. 1260 *et seq.*).

(c) Nothing contained in this Act shall be construed as in any way affecting, modifying, repealing, or superseding the provisions of the virus, serum, and toxin Act of July 1, 1902 [now incorporated in Public Health Service Act of July 1, 1944, U. S. C., 1946 ed., title 42, ch. 6A, sec. 262]; the Filled Cheese Act of June 6, 1896 (U. S. C., 1946 ed., title 26, ch. 17, secs. 2350-2362); the Filled Milk Act of March 4, 1923 (U. S. C., 1946 ed., title 21, ch. 3, secs. 61-64); or the Import Milk Act of February 15, 1927 (U. S. C., 1946 ed., title 21, ch. 4, secs. 141-149).

(d) In order to carry out the provisions of this Act which take effect prior to the repeal of the Food and Drugs Act of June 30, 1906, as amended, appropriations available for the enforcement of such Act of June 30, 1906, are also authorized to be made available to carry out such provisions.

(Approved June 25, 1938.)

Public Law 201—83d Congress
Chapter 334—1st Session
H. R. 5016

AN ACT

To amend sections 502 (1) and 507 of the Federal Food, Drug, and Cosmetic Act in order to identify the drug known as aureomycin by its chemical name, chlortetracycline.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That section 502 (1) of the Federal Food, Drug, and Cosmetic Act (21 U. S. C., sec. 352 (1)) is amended by striking out "aureomycin" and inserting in lieu thereof "chlortetracycline".

SEC. 2. (a) The heading of section 507 of such Act (21 U. S. C., sec. 357) is amended by striking out "AUREOMYCIN" and inserting in lieu thereof "CHLORTETRACYCLINE".

(b) The first sentence of subsection (a) of such section 507 is amended by striking out "aureomycin" and inserting in lieu thereof "chlortetracycline".

Approved August 5, 1953.

Public Law 335—83d Congress
Chapter 143—2d Session
H. R. 6434

AN ACT

To amend sections 401 and 701 of the Federal Food, Drug, and Cosmetic Act so as to simplify the procedures governing the establishment of food standards.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That section 401 of the Federal Food, Drug, and Cosmetic Act (21 U. S. C., sec. 341), is amended by inserting "(a)" after "SEC. 401." and by adding at the end of such section the following new subsection:

"(b) (1) Any action under subsection (a) for the issuance, amendment, or repeal of

¹⁷ See footnote 11, page 902.

any regulation shall be begun by a proposal made (A) by the Secretary of his own initiative, or (B) by petition of any interested person, showing reasonable grounds therefor, filed with the Secretary. The Secretary shall publish such proposal and shall afford all interested persons an opportunity to present their views thereon, orally or in writing. As soon as practicable thereafter, the Secretary shall by order act upon such proposal and shall make such order public. Except as provided in paragraph (2), the order shall become effective at such time as may be specified therein, but not prior to the day following the last day on which objections may be filed under such paragraph.

“(2) At any time prior to the thirtieth day after the date on which an order entered under paragraph (1) is made public, any person who will be adversely affected by such order if placed in effect may file objections thereto with the Secretary, specifying with particularity the provisions of the order deemed objectionable, stating the grounds therefor, and requesting a public hearing upon such objections. Until final action upon such objections is taken by the Secretary under paragraph (3), the filing of such objections shall operate to stay the effectiveness of those provisions of the order to which the objections are made. As soon as practicable after the time for filing objections has expired the Secretary shall publish a notice in the Federal Register specifying those parts of the order which have been stayed by the filing of objections and, if no objections have been filed, stating that fact.

“(3) As soon as practicable after such request for a public hearing, the Secretary, after due notice, shall hold such a public hearing for the purpose of receiving evidence relevant and material to the issues raised by such objections. At the hearing, any interested person may be heard in person or by representative. As soon as practicable after completion of the hearing, the Secretary shall by order act upon such objections and make such order public. Such order shall be based only on substantial evidence of record at such hearing and shall set forth, as part of the order, detailed findings of fact on which the order is based. The Secretary shall specify in the order the date on which it shall take effect, except that it shall not be made to take effect prior to the ninetieth day after its publication unless the Secretary finds that emergency conditions exist necessitating an earlier effective date, in which event the Secretary shall specify in the order his findings as to such conditions. Such order shall be subject to the provisions of section 701 (f) and (g).”

SEC. 2. Section 701 (e) of the Federal Food, Drug, and Cosmetic Act is amended by striking out “401,”.

SEC. 3. In any case in which, prior to the date of the enactment of this Act, a public hearing has been begun, in accordance with section 701 (e) of the Federal Food, Drug, and Cosmetic Act, upon a proposal to issue, amend, or repeal any regulation contemplated by section 401 of such Act, the provisions of such Act, as in force immediately prior to the date of the enactment of this Act, shall be applicable as though this Act had not been enacted.

Approved April 15, 1954.

Public Law 518—83d Congress
Chapter 559—2d Session
H. R. 7125
AN ACT

To amend the Federal Food, Drug, and Cosmetic Act with respect to residues of pesticide chemicals in or on raw agricultural commodities.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That section 201 of the Federal Food, Drug, and Cosmetic Act is amended by adding at the end thereof the following new paragraphs:

“(q) The term ‘pesticide chemical’ means any substance which, alone, in chemical combination or in formulation with one or more other substances, is an ‘economic poison’ within the meaning of the Federal Insecticide, Fungicide, and Rodenticide Act (7 U. S. C., secs. 135–135k) as now in force or as hereafter amended, and which is used in the production, storage, or transportation of raw agricultural commodities.

“(r) The term ‘raw agricultural commodity’ means any food in its raw or natural state, including all fruits that are washed, colored, or otherwise treated in their unpeeled natural form prior to marketing.”

SEC. 2. Clause (2) of section 402 (a) of the Federal Food, Drug, and Cosmetic Act is amended to read as follows: “(2) if it bears or contains any added poisonous or added deleterious substance, except a pesticide chemical in or on a raw agricultural commodity, which is unsafe within the meaning of section 406, or if it is a raw agricultural commodity and it bears or contains a pesticide chemical which is unsafe within the meaning of section 408 (a);”.

SEC. 3. Chapter IV of the Federal Food, Drug, and Cosmetic Act is amended by adding at the end thereof the following new section:

“TOLERANCES FOR PESTICIDE CHEMICALS IN OR ON RAW AGRICULTURAL COMMODITIES

“Sec. 408. (a) Any poisonous or deleterious pesticide chemical, or any pesticide chemical which is not generally recognized, among experts qualified by scientific training and experience to evaluate the safety of pesticide chemicals, as safe for use, added to a raw agricultural commodity, shall be deemed unsafe for the purposes of the application of clause (2) of section 402 (a) unless—

“(1) a tolerance for such pesticide chemical in or on the raw agricultural commodity has been prescribed by the Secretary of Health, Education, and Welfare under this section and the quantity of such pesticide chemical in or on the raw agricultural commodity is within the limits of the tolerance so prescribed; or

“(2) with respect to use in or on such raw agricultural commodity, the pesticide chemical has been exempted from the requirement of a tolerance by the Secretary under this section.

While a tolerance or exemption from tolerance is in effect for a pesticide chemical with respect to any raw agricultural commodity, such raw agricultural commodity shall not, by reason of bearing or containing any added amount of such pesticide chemical, be considered to be adulterated within the meaning of clause (1) of section 402 (a).

“(b) The Secretary shall promulgate regulations establishing tolerances with respect to the use in or on raw agricultural commodities of poisonous or deleterious pesticide chemicals and of pesticide chemicals which are not generally recognized, among experts qualified by scientific training and experience to evaluate the safety of pesticide chemicals, as safe for use, to the extent necessary to protect the public health. In establishing any such regulation, the Secretary shall give appropriate consideration, among other relevant factors, (1) to the necessity for the production of an adequate, wholesome, and economical food supply; (2) to the other ways in which the consumer may be affected by the same pesticide chemical or by other related substances that are poisonous or deleterious; and (3) to the opinion of the Secretary of Agriculture as submitted with a certification of usefulness under subsection (1) of this section. Such regulations shall be promulgated in the manner

prescribed in subsection (d) or (e) of this section. In carrying out the provisions of this section relating to the establishment of tolerances, the Secretary may establish the tolerance applicable with respect to the use of any pesticide chemical in or on any raw agricultural commodity at zero level if the scientific data before the Secretary does not justify the establishment of a greater tolerance.

“(c) The Secretary shall promulgate regulations exempting any pesticide chemical from the necessity of a tolerance with respect to use in or on any or all raw agricultural commodities when such a tolerance is not necessary to protect the public health. Such regulations shall be promulgated in the manner prescribed in subsection (d) or (e) of this section.

“(d) (1) Any person who has registered, or who has submitted an application for the registration of, an economic poison under the Federal Insecticide, Fungicide, and Rodenticide Act may file with the Secretary of Health, Education, and Welfare, a petition proposing the issuance of a regulation establishing a tolerance for a pesticide chemical which constitutes, or is an ingredient of, such economic poison, or exempting the pesticide chemical from the requirement of a tolerance. The petition shall contain data showing—

“(A) the name, chemical identity, and composition of the pesticide chemical;

“(B) the amount, frequency, and time of application of the pesticide chemical;

“(C) full reports of investigations made with respect to the safety of the pesticide chemical;

“(D) the results of tests on the amount of residue remaining, including a description of the analytical methods used;

“(E) practicable methods for removing residue which exceeds any proposed tolerance;

“(F) proposed tolerances for the pesticide chemical if tolerances are proposed; and

“(G) reasonable grounds in support of the petition.

Samples of the pesticide chemical shall be furnished to the Secretary upon request. Notice of the filing of such petition shall be published in general terms by the Secretary within thirty days after filing. Such notice shall include the analytical methods available for the determination of the residue of the pesticide chemical for which a tolerance or exemption is proposed.

“(2) Within ninety days after a certification of usefulness by the Secretary of Agriculture under subsection (1) with respect to the pesticide chemical named in the petition, the Secretary of Health, Education, and Welfare shall, after giving due consideration to the data submitted in the petition or otherwise before him, by order make public a regulation—

“(A) establishing a tolerance for the pesticide chemical named in the petition for the purposes for which it is so certified as useful, or

“(B) exempting the pesticide chemical from the necessity of a tolerance for such purposes,

unless within such ninety-day period the person filing the petition requests that the petition be referred to an advisory committee or the Secretary within such period otherwise deems such referral necessary, in either of which events the provisions of paragraph (3) of this subsection shall apply in lieu hereof.

“(3) In the event that the person filing the petition requests, within ninety days after a certification of usefulness by the Secretary of Agriculture under subsection (1) with respect to the pesticide chemical named in the petition, that the petition be referred to an advisory committee, or in the event the Secretary of Health, Education, and Welfare within such period otherwise deems such referral necessary, the

Secretary of Health, Education, and Welfare shall forthwith submit the petition and other data before him to an advisory committee to be appointed in accordance with subsection (g) of this section. As soon as practicable after such referral, but not later than sixty days thereafter, unless extended as hereinafter provided, the committee shall, after independent study of the data submitted to it by the Secretary and other data before it, certify to the Secretary a report and recommendations on the proposal in the petition to the Secretary, together with all underlying data and a statement of the reasons or basis for the recommendations. The sixty-day period provided for herein may be extended by the advisory committee for an additional thirty days if the advisory committee deems this necessary. Within thirty days after such certification, the Secretary shall, after giving due consideration to all data then before him, including such report, recommendations, underlying data, and statement, by order make public a regulation—

“(A) establishing a tolerance for the pesticide chemical named in the petition for the purposes for which it is so certified as useful; or

“(B) exempting the pesticide chemical from the necessity of a tolerance for such purposes.

“(4) The regulations published under paragraph (2) or (3) of this subsection will be effective upon publication.

“(5) Within thirty days after publication, any person adversely affected by a regulation published pursuant to paragraph (2) or (3) of this subsection, or pursuant to subsection (e), may file objections thereto with the Secretary, specifying with particularity the provisions of the regulation deemed objectionable, stating reasonable grounds therefor, and requesting a public hearing upon such objections. A copy of the objections filed by a person other than the petitioner shall be served on the petitioner, if the regulation was issued pursuant to a petition. The petitioner shall have two weeks to make a written reply to the objections. The Secretary shall thereupon, after due notice, hold such public hearing for the purpose of receiving evidence relevant and material to the issues raised by such objections. Any report, recommendations, underlying data, and reasons certified to the Secretary by an advisory committee shall be made a part of the record of the hearing, if relevant and material, subject to the provisions of section 7 (c) of the Administrative Procedure Act (5 U. S. C., sec. 1006 (c)). The National Academy of Sciences shall designate a member of the advisory committee to appear and testify at any such hearing with respect to the report and recommendations of such committee upon request of the Secretary, the petitioner, or the officer conducting the hearing: *Provided*, That this shall not preclude any other member of the advisory committee from appearing and testifying at such hearing. As soon as practicable after completion of the hearing, the Secretary shall act upon such objections and by order make public a regulation. Such regulation shall be based only on substantial evidence of record at such hearing, including any report, recommendations, underlying data, and reasons certified to the Secretary by an advisory committee, and shall set forth detailed findings of fact upon which the regulation is based. No such order shall take effect prior to the ninetieth day after its publication, unless the Secretary finds that emergency conditions exist necessitating an earlier effective date, in which event the Secretary shall specify in the order his findings as to such conditions.

“(e) The Secretary may at any time, upon his own initiative or upon the request of any interested person, propose the issuance of a regulation establishing a tolerance for a pesticide chemical or exempting it from the necessity of a tolerance. Thirty days after publication of such a proposal, the Secretary may by order publish a

regulation based upon the proposal which shall become effective upon publication unless within such thirty-day period a person who has registered, or who has submitted an application for the registration of, an economic poison under the Federal Insecticide, Fungicide, and Rodenticide Act containing the pesticide chemical named in the proposal, requests that the proposal be referred to an advisory committee. In the event of such a request, the Secretary shall forthwith submit the proposal and other relevant data before him to an advisory committee to be appointed in accordance with subsection (g) of this section. As soon as practicable after such referral, but not later than sixty days thereafter, unless extended as hereinafter provided, the committee shall, after independent study of the data submitted to it by the Secretary and other data before it, certify to the Secretary a report and recommendations on the proposal together with all underlying data and a statement of the reasons or basis for the recommendations. The sixty-day period provided for herein may be extended by the advisory committee for an additional thirty days if the advisory committee deems this necessary. Within thirty days after such certification, the Secretary may, after giving due consideration to all data before him, including such report, recommendations, underlying data and statement, by order publish a regulation establishing a tolerance for the pesticide chemical named in the proposal or exempting it from the necessity of a tolerance which shall become effective upon publication. Regulations issued under this subsection shall upon publication be subject to paragraph (5) of subsection (d).

“(f) All data submitted to the Secretary or to an advisory committee in support of a petition under this section shall be considered confidential by the Secretary and by such advisory committee until publication of a regulation under paragraph (2) or (3) of subsection (d) of this section. Until such publication, such data shall not be revealed to any person other than those authorized by the Secretary or by an advisory committee in the carrying out of their official duties under this section.

“(g) Whenever the referral of a petition or proposal to an advisory committee is requested under this section, or the Secretary otherwise deems such referral necessary the Secretary shall forthwith appoint a committee of competent experts to review the petition or proposal and to make a report and recommendations thereon. Each such advisory committee shall be composed of experts, qualified in the subject matter of the petition and of adequately diversified professional background selected by the National Academy of Sciences and shall include one or more representatives from land-grant colleges. The size of the committee shall be determined by the Secretary. Members of an advisory committee shall receive as compensation for their services a reasonable per diem, which the Secretary shall by rules and regulations prescribe, for time actually spent in the work of the committee, and shall in addition be reimbursed for their necessary traveling and subsistence expenses while so serving away from their places of residence. The members shall not be subject to any other provisions of law regarding the appointment and compensation of employees of the United States. The Secretary shall furnish the committee with adequate clerical and other assistance, and shall by rules and regulations prescribe the procedure to be followed by the committee.

“(h) A person who has filed a petition or who has requested the referral of a proposal to an advisory committee in accordance with the provisions of this section, as well as representatives of the Department of Health, Education, and Welfare, shall have the right to consult with any advisory committee provided for in subsection (g) in connection with the petition or proposal.

“(i) (1) In a case of actual controversy as to the validity of any order under sub-

section (d) (5), (e), or (l) any person who will be adversely affected by such order may obtain judicial review by filing in the United States Court of Appeals for the circuit wherein such person resides or has his principal place of business, or in the United States Court of Appeals for the District of Columbia Circuit, within sixty days after the entry of such order, a petition praying that the order be set aside in whole or in part.

“(2) In the case of a petition with respect to an order under subsection (d) (5) or (e), a copy of the petition shall be forthwith served upon the Secretary, or upon any officer designated by him for that purpose, and thereupon the Secretary shall certify and file in the court a transcript of the proceedings and the record on which he based his order. Upon such filing, the court shall have exclusive jurisdiction to affirm or set aside the order complained of in whole or in part. The findings of the Secretary with respect to questions of fact shall be sustained if supported by substantial evidence when considered on the record as a whole, including any report and recommendation of an advisory committee.

“(3) In the case of a petition with respect to an order under subsection (l), a copy of the petition shall be forthwith served upon the Secretary of Agriculture, or upon any officer designated by him for that purpose, and thereupon the Secretary shall certify and file in the court a transcript of the proceedings and the record on which he based his order. Upon such filing, the court shall have exclusive jurisdiction to affirm or set aside the order complained of in whole or in part. The findings of the Secretary with respect to questions of fact shall be sustained if supported by substantial evidence when considered on the record as a whole.

“(4) If application is made to the court for leave to adduce additional evidence, the court may order such additional evidence to be taken before the Secretary of Health, Education, and Welfare or the Secretary of Agriculture, as the case may be, and to be adduced upon the hearing in such manner and upon such terms and conditions as to the court may seem proper, if such evidence is material and there were reasonable grounds for failure to adduce such evidence in the proceedings below. The Secretary of Health, Education, and Welfare or the Secretary of Agriculture, as the case may be, may modify his findings as to the facts and order by reason of the additional evidence so taken, and shall file with the court such modified findings and order.

“(5) The judgment of the court affirming or setting aside, in whole or in part, any order under this section shall be final, subject to review by the Supreme Court of the United States upon certiorari or certification as provided in section 1254 of title 28 of the United States Code. The commencement of proceedings under this section shall not, unless specifically ordered by the court to the contrary, operate as a stay of an order. The courts shall advance on the docket and expedite the disposition of all causes filed therein pursuant to this section.

“(j) The Secretary may, upon the request of any person who has obtained an experimental permit for a pesticide chemical under the Federal Insecticide, Fungicide, and Rodenticide Act or upon his own initiative, establish a temporary tolerance for the pesticide chemical for the uses covered by the permit whenever in his judgment such action is deemed necessary to protect the public health, or may temporarily exempt such pesticide chemical from a tolerance. In establishing such a tolerance, the Secretary shall give due regard to the necessity for experimental work in developing an adequate, wholesome, and economical food supply and to the limited hazard to the public health involved in such work when conducted in accordance

with applicable regulations under the Federal Insecticide, Fungicide, and Rodenticide Act.

“(k) Regulations affecting pesticide chemicals in or on raw agricultural commodities which are promulgated under the authority of section 406 (a) upon the basis of public hearings instituted before January 1, 1953, in accordance with section 701 (e), shall be deemed to be regulations under this section and shall be subject to amendment or repeal as provided in subsection (m).

“(1) The Secretary of Agriculture, upon request of any person who has registered, or who has submitted an application for the registration of, an economic poison under the Federal Insecticide, Fungicide, and Rodenticide Act, and whose request is accompanied by a copy of a petition filed by such person under subsection (d) (1) with respect to a pesticide chemical which constitutes, or is in ingredient of, such economic poison, shall, within thirty days or within sixty days if upon notice prior to the termination of such thirty days the Secretary deems it necessary to postpone action for such period, on the basis of data before him, either—

“(1) certify to the Secretary of Health, Education, and Welfare that such pesticide chemical is useful for the purpose for which a tolerance or exemption is sought; or

“(2) notify the person requesting the certification of his proposal to certify that the pesticide chemical does not appear to be useful for the purpose for which a tolerance or exemption is sought, or appears to be useful for only some of the purposes for which a tolerance or exemption is sought.

In the event that the Secretary of Agriculture takes the action described in clause (2) of the preceding sentence, the person requesting the certification, within one week after receiving the proposed certification, may either (A) request the Secretary of Agriculture to certify to the Secretary of Health, Education, and Welfare on the basis of the proposed certification; (B) request a hearing on the proposed certification or the parts thereof objected to; or (C) request both such certification and such hearing. If no such action is taken, the Secretary may by order make the certification as proposed. In the event that the action described in clause (A) or (C) is taken, the Secretary shall by order make the certification as proposed with respect to such parts thereof as are requested. In the event a hearing is requested, the Secretary of Agriculture shall provide opportunity for a prompt hearing. The certification of the Secretary of Agriculture as the result of such hearing shall be made by order and shall be based only on substantial evidence of record at the hearing and shall set forth detailed findings of fact. In no event shall the time elapsing between the making of a request for a certification under this subsection and final certification by the Secretary of Agriculture exceed one hundred and sixty days. The Secretary shall submit to the Secretary of Health, Education, and Welfare with any certification of usefulness under this subsection an opinion, based on the data before him, whether the tolerance or exemption proposed by the petitioner reasonably reflects the amount of residue likely to result when the pesticide chemical is used in the manner proposed for the purpose for which the certification is made. The Secretary of Agriculture, after due notice and opportunity for public hearing, is authorized to promulgate rules and regulations for carrying out the provisions of this subsection.

“(m) The Secretary of Health, Education, and Welfare shall prescribe by regulations the procedure by which regulations under this section may be amended or repealed, and such procedure shall conform to the procedure provided in this section for the promulgation of regulations establishing tolerances, including the appoint-

ment of advisory committees and the procedure for referring petitions to such committees.

“(n) The provisions of section 303 (c) of the Federal Food, Drug, and Cosmetic Act with respect to the furnishing of guaranties shall be applicable to raw agricultural commodities covered by this section.

“(o) The Secretary of Health, Education, and Welfare shall by regulation require the payment of such fees as will in the aggregate, in the judgment of the Secretary, be sufficient over a reasonable term to provide, equip, and maintain an adequate service for the performance of the Secretary’s functions under this section. Under such regulations, the performance of the Secretary’s services or other functions pursuant to this section, including any one or more of the following, may be conditioned upon the payment of such fees: (1) The acceptance of filing of a petition submitted under subsection (d); (2) the promulgation of a regulation establishing a tolerance, or an exemption from the necessity of a tolerance, under this section, or the amendment or repeal of such a regulation; (3) the referral of a petition or proposal under this section to an advisory committee; (4) the acceptance for filing of objections under subsection (d) (5); or (5) the certification and filing in court of a transcript of the proceedings and the record under subsection (i) (2). Such regulations may further provide for waiver or refund of fees in whole or in part when in the judgment of the Secretary such waiver or refund is equitable and not contrary to the purposes of this subsection.”

SEC. 4. There are hereby authorized to be appropriated, out of any moneys in the Treasury not otherwise appropriated, such sums as may be necessary for the purpose and administration of this Act.

SEC. 5. This Act shall take effect upon the date of its enactment, except that with respect to pesticide chemicals for which tolerances or exemptions have not been established under section 408 of the Federal Food, Drug, and Cosmetic Act, the amendment to section 402 (a) of such Act made by section 2 of this Act shall not be effective—

- (1) for the period of one year following the date of the enactment of this Act; or
- (2) for such additional period following such period of one year, but not extending beyond two years after the date of the enactment of this Act, as the Secretary of Health, Education, and Welfare may prescribe on the basis of a finding that conditions exist which necessitate the prescribing of such additional period.

Approved July 22, 1954.

B. FEDERAL DEFINITIONS AND STANDARDS FOR FOOD

Sec. 401 of the Federal Food, Drug and Cosmetic Act (1938) provides authority to the administrator to promulgate regulations fixing and establishing for any food, under its common or usual name as far as practicable, a reasonable standard of quality, and/or reasonable standard of fill of container. Such standards seek to promote honesty and fair dealing in the interest of the consumer.

Up to the present time definitions and standards have been issued for cacao products, cereal flours and related products, elementary pastes, milk and cream, cheeses, canned fruit, fruit preserves and jellies, fruit butters, shellfish, eggs and egg products, oleomargarine, canned vegetables, tomato products, bakery products, dressings for foods.

Copies of official standards can be obtained by addressing the Food and Drug Administration, Dept. of Health, Education and Welfare, Washington (25), D. C.

**C. DIETARY REGULATIONS COVERING LABEL STATEMENTS ON FOODS
FOR SPECIAL DIETARY USES (FED. REG. C: 5921 (11/22/41))**

[Docket No. FDC-24]

**PART 125—LABEL STATEMENTS CONCERNING DIETARY PROPERTIES OF FOOD PUR-
PORTING TO BE OR REPRESENTED FOR SPECIAL DIETARY USES**

FINDINGS OF FACT AND REGULATIONS

By virtue of the authority vested in the Federal Security Administrator by provisions of the Federal Food, Drug, and Cosmetic Act [Sec. 403 (j), 52 Stat. 1048, 21 U.S.C., Sup. V, 343 (j); Sec. 701 (e), 52 Stat. 1055, 21 U.S.C., Sup. V, 371 (e)], the Reorganization Act of 1939 (53 Stat. 561 ff.; 5 U.S.C., Sup. V, 133 ff.), and Reorganization Plans No. I (53 Stat. 1423, 4 F.R. 2727) and No. IV (54 Stat., 5 F.R. 2421); and upon the basis of evidence of record at the above entitled hearing duly held pursuant to notice thereof issued by the Administrator on August 31, 1940 (5 F.R. 3565), the following order is hereby promulgated:

Findings of Fact

1. The value of a food for any special dietary use is determined by its dietary properties, such as the presence or absence of a substance or the quantity or altered character of a constituent.

2. Information necessary in order to inform the purchaser of the value of a food for a special dietary use includes a statement of the dietary properties upon which its value for such use is based.

3. Among other dietary properties of food, certain vitamins and minerals are known to be essential to the normal functioning of the human organism; the quantity of any vitamin or mineral required is customarily expressed in terms of the quantity required each day and is referred to as the daily requirement.

4. Deficiency in the intake of any essential vitamin, mineral, or other dietary property produces pathological conditions known as a deficiency disease, whereas, intake of a certain minimum quantity of such substance prevents the onset of such conditions.

5. The value of a food for special dietary use may depend on its suitability for the treatment of a deficiency disease.

6. The quantity of a vitamin, mineral or other dietary property necessary to prevent a deficiency disease is usually less than the quantity necessary for the effective treatment of that disease.

7. The quantity and the duration of administration of such a property for the correction of such disease may differ under different conditions.

8. Purchasers in general are unaware of the quantities of dietary constituents or the duration of their consumption necessary for the effective treatment of deficiency diseases.

9. Information required by the purchaser to evaluate a food for the correction of deficiency diseases includes adequate directions for use.

10. The value of a food for special dietary use may depend on its content of one or more of the vitamins A (or precursors thereof), B₁, C, D, riboflavin, nicotinic acid or nicotinic acid amide, and some other vitamins.

11. The terms "vitamin B₁" and "thiamine," the terms "vitamin C" and "ascorbic acid", and the terms "riboflavin", "vitamin B₂" and "vitamin G", are synonymous.

12. Deficiency in the intake of vitamin A produces the pathological conditions known as nutritional night blindness and as xerophthalmia.

13. Vitamin A exists as such in certain animal tissues and is produced by the animal organism from precursors of vitamin A, which include the vegetable pigments alpha carotene, beta carotene, gamma carotene, and cryptoxanthin.

14. The vitamin A activity of food is determined by biological assay; an equal weight of vitamin A and of each of its known precursors, when reacted upon by the animal organism, do not all have the same degree of activity; none of such precursors has as high a degree of activity as vitamin A.

15. It is necessary, in order fully to inform the purchaser of the value of the precursors of vitamin A for special dietary use, that their activity be measured and stated as vitamin A, but that any such precursor sold as such be designated by its common or usual name and not as vitamin A.

16. Deficiency in the intake of vitamin B₁ produces the pathological condition known as beriberi.

17. Deficiency in the intake of vitamin C produces the pathological condition known as scurvy.

18. Deficiency in the intake of vitamin D produces the pathological conditions known as rickets and osteoporosis.

19. Deficiency in the intake of riboflavin produces the pathological condition known as ariboflavinosis.

20. The value of a food for special dietary use may depend on its content of one or more of the mineral elements calcium, phosphorus, iron, iodine, and possibly other mineral elements.

21. Deficiency in the intake of calcium or phosphorus produces the pathological conditions known as rickets and osteoporosis.

22. Deficiency in the intake of iron results in the pathological condition known as nutritional anemia.

23. Deficiency in the intake of iodine results in the pathological condition known as simple goiter.

24. The minimum daily requirements for such vitamins and minerals in the human diet are the quantities necessary for the prevention of such deficiency diseases.

25. The requirements of different persons for most of the essential vitamins bear a relationship to body weight which in turn bears a relationship to age groups. Thus, for nutritional purposes, with respect to these and many other dietary factors, persons are commonly classed as infants (persons under one year of age), children (persons one or more but less than 12 years of age), and adults (persons 12 or more years of age); children may be further classified as the groups less than six, and six or more years of age, when nutritional requirements bear an unusually close relationship to body weight.

26. The nutritional requirements for vitamins A, B₁, C, and riboflavin are so correlated with age, but the requirements for vitamin D and minerals are not.

27. Purchasers generally do not know the quantity of vitamins and minerals needed to supply their minimum daily requirements.

28. Information necessary for the purchaser to evaluate a food for special dietary use based on its vitamin or mineral property for which the minimum daily requirement has been established is a statement of the proportion of the minimum daily requirement for such vitamin or mineral supplied by a specified quantity of such food.

29. To be reasonably useful to the purchaser, the quantity so specified must be the quantity of the food customarily or usually consumed during a period of one day,

or a quantity reasonably suitable for or practicable of consumption during a period of one day.

30. The quantity of vitamin A in a food is expressed as the biologically measured activity of vitamin A and its precursors in terms of United States Pharmacopoeia units (commonly referred to as U.S.P. units).

31. The quantity of vitamin B₁ in a food is expressed by weight in terms of the metric system or by United States Pharmacopoeia units (commonly referred to as U. S. P. units).

32. The quantity of vitamin C in a food is expressed by weight in terms of the metric system or by United States Pharmacopoeia units (commonly referred to as U. S. P. units).

33. The quantity of vitamin D in a food is expressed in terms of United States Pharmacopoeia units (commonly referred to as U. S. P. units).

34. The quantity of riboflavin in a food is expressed by weight in terms of the metric system.

35. The quantities of calcium, phosphorus, iron, and iodine in foods are commonly expressed by weight in terms of the metric system.

36. Because of variations in body weight and other factors, the minimum daily requirements of individuals for vitamins vary, even among persons in the same age groups; but in the cases of vitamins A, B₁, C, D, and riboflavin the variation within any age group is of such narrow range that a minimum daily requirement for any such vitamin can be prescribed for different age groups, and the ingestion of the quantity so prescribed will prevent any clinically significant manifestation of the deficiency disease characteristic of deficiency of such vitamin.

37. The minimum daily requirement for vitamin A is as follows:

For infants, 1,500 U. S. P. units.

For children more than 1 but less than 12 years of age, 3,000 U. S. P. units.

For any person 12 or more years of age, 4,000 U. S. P. units.

38. The minimum daily requirement for vitamin B₁ is as follows:

For infants, 0.25 mg. (83 U. S. P. units).

For children more than 1 but less than 6 years, 0.5 mg. (167 U. S. P. units).

For children 6 or more but less than 12 years old, 0.75 mg. (250 U. S. P. units).

For a person 12 or more years old, 1 mg. (333 U. S. P. units).

39. The minimum daily requirement for vitamin C is as follows:

For infants, 10 mg. (200 U. S. P. units).

For children more than 1 but less than 12 years old, 20 mg. (400 U. S. P. units).

For a person 12 or more years old, 30 mg. (600 U. S. P. units).

40. The minimum daily requirement for vitamin D is 400 units for any person, irrespective of age, except as hereinafter noted in respect of vitamin D contained in cow's milk and evaporated milk.

41. The minimum daily requirement for riboflavin is as follows:

For an infant, 0.5 mg.

For a person 12 or more years old, 2.0 mg.

42. The minimum daily requirement for riboflavin for children one year or more but less than 12 years of age has not been established.

43. A given quantity of vitamin D consumed in cows' milk or evaporated milk is more efficacious in the prevention of rickets than the same quantity of vitamin D consumed in other carriers, but the minimum daily requirement of vitamin D when consumed in cows' milk or evaporated milk has not been established.

44. Cows' milk containing 135 units of vitamin D per quart, and evaporated milk

containing 7.5 U. S. P. units of vitamin D per avoirdupois ounce, usually will prevent clinical rickets when fed to normal infants in customary quantities.

45. Cows' milk and evaporated milk with increased vitamin D content are customarily marketed at two levels of vitamin D content, 400 U. S. P. units and 135 U. S. P. units per quart in the case of milk, and 22.2 U. S. P. units and 7.5 U. S. P. units per avoirdupois ounce in the case of evaporated milk.

46. In the absence of established fact as to the minimum daily requirement for vitamin D carried in cows' milk and evaporated milk, information essential to the purchaser concerning the value of such milk and evaporated milk for special dietary use based on its vitamin D content includes at least a statement of the number of U. S. P. units of vitamin D in specified quantity of such milk or evaporated milk.

47. The prevalence of rickets among infants and children is such that information essential to purchasers concerning the value of cows' milk for special dietary use based on a vitamin D content increased to less than 135 U. S. P. units per quart, includes at least the statement that additional vitamin D should be supplied from other sources.

48. Because of variations in body weight, in the quantity of food ingested, and in other factors, it is impracticable to establish minimum daily requirements applicable to the needs of infants generally for calcium, phosphorus, iron, and iodine.

49. Because of variations in the body weight and other factors, individuals other than infants have varying minimum daily requirements for minerals. In the cases of calcium, phosphorus, iron, and iodine, the variation is of such narrow range that a minimum daily requirement for any such mineral can be prescribed, and the ingestion of the quantity so prescribed will prevent any clinically significant manifestation of the deficiency disease characteristic of a deficiency of such mineral, except as specified in Finding 50 with respect to pregnant and lactating women.

50. During pregnancy and lactation the requirements of women for calcium, phosphorus, and iron are increased.

51. The minimum daily requirement for calcium and for phosphorus is 750 milligrams for any person more than one year of age, except any pregnant or lactating woman for whom 1.5 grams is the minimum daily requirement.

52. The minimum daily requirement for iron is 7.5 milligrams for a child more than one but less than six years of age, 10 milligrams for a person six or more years of age, except any pregnant or lactating woman for whom 15 milligrams is the minimum daily requirement.

53. The minimum daily requirement for iodine is 0.1 milligram for any person more than one year of age.

54. In order fully to inform purchasers of the value of a food purporting to be or represented for special dietary use by pregnant or lactating women based in whole or in part on its mineral property in respect of calcium, phosphorus, or iron, a statement of the proportion of the minimum daily requirement furnished thereby must include the proportion for such women.

55. Simple goiter is endemic to certain geographical areas in the United States, because of the inadequacy of the iodine content of the water and other foods in those areas.

56. Federal and state public health authorities seek to encourage and increase the consumption of iodine in those areas.

57. As a means of supplying adequate quantities of iodine to the diet in those areas, such authorities have induced the manufacturers of salt, inasmuch as salt is common to all adequate diets, to produce iodized salt by the addition to salt, of 0.023 percent by weight of potassium iodide, equivalent to 0.0176 percent iodine.

58. The distribution of iodized salt has resulted in a great decrease in the incidence of simple goiter in those areas.

59. Under the program so agreed upon between health authorities and salt manufacturers, the quantity of iodine in the usual daily intake of iodized salt is approximately 10 times the minimum daily requirement for iodine of persons other than infants.

60. The statement on the label of iodized salt that the usual daily intake thereof contains 10 times the minimum daily requirement for iodine would be reasonably calculated to result in a decrease in the consumption of iodized salt, even in those areas where goiter is endemic, and thus cause an increase in the incidence of simple goiter.

61. It is the established practice of manufacturers of iodized salt to declare on the label the percent by weight of potassium iodide in the iodized salt.

62. Purchasers of iodized salt are adequately informed of its value in the prevention of simple goiter by the declaration on the label of the percent by weight of potassium iodide present therein.

63. In the consumption of vitamins and minerals it is desirable to have a safety factor above the minimum daily requirements, and fractional proportions of requirements above the minimum daily requirements for vitamins and minerals may be regarded as such a safety factor.

64. Such fractions may be disregarded in label statements without depriving the purchaser of essential information.

65. The dietary requirements of age groups other than adults are usually estimated by reference to adult intakes as a standard.

66. A statement of the proportion of the minimum daily requirements of adults for vitamins and minerals suffices to furnish full information as to such requirements for persons generally; but, where the food is for the use of a specific age group or groups, full information as to its value for such use includes a statement of the proportion of the minimum daily requirement for such vitamin or mineral for such age group or groups.

67. A food may have special dietary use by reason of its content of some vitamins other than A, B₁, C, D, or riboflavin, or some minerals other than calcium, phosphorus, iron, or iodine. The minimum daily requirements and, in some cases, the need in human nutrition for such other substances have not been established by the opinion of experts qualified by scientific training and experience to determine such facts; but in the cases of some such other substances there is substantial, though inconclusive, support in the opinions of such experts of a determination of one or both of such facts.

68. When the need for such a substance has not been so established, information necessary fully to inform the purchaser of the value for special dietary use of a food containing it includes a statement that the need for such substance has not been established.

69. When the need for a vitamin or mineral has been so established, it is frequently still unknown what is the minimum daily requirement therefor.

70. When the minimum daily requirement for such a substance has not been established, whether or not evidence of human need therefor is conclusive, purchasers must rely on the best available scientific information or professional advice; and in order to evaluate such food in terms of such information or advice, it is necessary that the purchaser be informed of the quantity of the vitamin or mineral present in a specified quantity of such food suitable for daily consumption.

71. The quantity of such a vitamin or mineral necessary to prevent a disease re-

sulting from a dietary deficiency of such substance, is usually unrelated to the quantity necessary for use in treating the disease; when such a vitamin or mineral purports to be or is represented for use in treating such a disease, in addition to adequate directions for use, a statement of the quantity of the substance present in a specified quantity of the food is information necessary for the purchaser to evaluate the food for such use in terms of the best available scientific information or professional advice.

72. The value of a food for special dietary use may depend on its suitability as a food for infants.

73. The diet of infants is more restricted than that of normal persons of other age groups and the suitability of a food for infant use depends on its ingredients or character.

74. Information necessary fully to inform the purchaser of the value of a food for such use includes the common or usual name of each ingredient thereof.

75. Infants are more susceptible to allergies resulting from plant or animal substances than persons of other age groups.

76. Information concerning the source of a food of plant or animal origin for use by infants is necessary properly to evaluate its suitability for use by particular infants.

77. The value of an infant food may depend upon its simulation of, or suitability as a complete or partial substitute for, human milk.

78. Normal human milk contains adequate quantities of all the factors essential to infant nutrition, except that its content of vitamin C, vitamin D, and iron is insufficient in many cases to prevent scurvy, rickets, and nutritional anemia, respectively.

79. The value of a food as a complete or partial substitute for human milk in infant feeding depends on its content of such factors as moisture, protein, fat, carbohydrates, crude fiber, calcium, phosphorous, iron, and vitamins A, B₁, C, and D, and the calories supplied by such food.

80. Information necessary to evaluate a food as a complete or partial substitute for human milk in infant feeding includes a statement of the percent by weight of moisture, protein, fat available carbohydrates, crude fiber, calcium, phosphorous, and iron, a statement of the number of available calories, and a statement of the number of units of vitamin A, vitamin B₁, vitamin C, and vitamin D supplied by the food.

81. The most common dietary deficiency diseases in infants are scurvy, rickets, and nutritional anemia, caused respectively by deficiencies of vitamin C, vitamin D, and iron in human milk or in preparations used as substitutes for human milk, including, among others, cows' milk and evaporated milk in which the quantities of such substances have not been increased.

82. Many purchasers are unaware of the deficiencies in these respects of such substitutes.

83. Such substitutes are customarily diluted and mixed with a soluble carbohydrate for infant feeding. In the proportions usually recommended by pediatricians each 100 calories of the mixed substitute must contain 30 U. S. P. units of vitamin C, 50 U. S. P. units of vitamin D, and 0.75 milligram of iron to supply the minimum daily requirements of infants for such substances.

84. Where a food for use as a complete or partial substitute for human milk in infant feeding contains less than such quantities of vitamin C, vitamin D, or iron, information necessary for the purchaser to determine the value of the food includes a statement that such factors must be supplemented from other sources.

85. The value of cows' milk and evaporated milk used as a complete or partial substitute for human milk in infant feeding is sufficiently well known that, aside from their deficiency in vitamin C, iron, and vitamin D when the quantity of vitamin D has not been adequately increased, a statement relative to their constituents is not necessary to inform the purchaser of their value for such use.

86. 135 U. S. P. units of vitamin D per quart of cows' milk and 7.5 U. S. P. units per avoirdupois ounce of evaporated milk, the equivalent of 135 units per quart of milk when the evaporated milk is reconstituted by the addition of water, being usually sufficient, when fed in customary quantities, for the prevention of clinical rickets in normal infants due to its greater efficacy in milk, a statement that vitamin D must be supplied from other sources is not necessary when the milk or evaporated milk contains such quantities of vitamin D.

87. The value of food for special dietary use may depend on its suitability for use in the control of body weight through regulating the intake of protein, fat, carbohydrates, or calories.

88. The quantity and relative proportions of protein, fat, and carbohydrates, and the number of calories consumed, are important factors in the regulation of body weight.

89. The value of a food for special dietary use may depend on its suitability for use in dietary management with respect to disease through regulating the intake of protein, fat, carbohydrates, or calories; such management is an important factor in the treatment of many diseases.

90. Some carbohydrate substances are not digested or assimilated by the human organism and supply no food energy. Only the carbohydrates which may be digested and assimilated are available to the metabolic processes of the organism.

91. Carbohydrates which are nonavailable to the metabolic processes have a theoretical caloric value but supply no calories to the human organism.

92. Information necessary for the purchaser to evaluate a food for use in the control of body weight, or in dietary management with respect to disease, includes a statement on the label of the percent by weight of protein, fat, and available carbohydrates in such food and a statement on the label of the number of available calories supplied by a specified quantity of the food.

93. The value of a food for special dietary use may depend on the presence therein of a constituent which is not utilized in normal metabolism and which consequently has no nutritive value.

94. Its use may be for the reduction of caloric intake, as in the case of mineral oil; for the promotion of laxation, as in the case of fibrous plant matter; or for the satisfaction of taste desires without increasing food value, as in the case of saccharin.

95. Information necessary to inform the purchaser of the value of a food for special dietary use by reason of its content of such a constituent includes a statement of the percent by weight of the constituent in the food, preceded or followed by the word "nonnutritive", except as hereinafter noted in Finding 98 with respect to saccharin.

96. If such constituent is fibrous plant matter it is commonly determined as and expressed as crude fiber.

97. Saccharin, alone or in combination in a saccharin salt, is a nonnutritive, synthetic sweetening substance sometimes used to satisfy the psychological desire for sweets in the diets of persons who must restrict their intake of carbohydrates. It has no other use as a food and is not utilized in normal metabolism.

98. Information necessary to inform the purchaser of the value of a food for special dietary use by reason of its saccharin content is a statement that it contains a specified

percent by weight of saccharin, a nonnutritive, artificial sweetener which should be used only by persons who must restrict their intake of ordinary sweets.

99. The value of a food for special dietary use may depend on its hypoallergenic property; that is, the absence of, or greatly reduced quantity of, a substance which causes allergic reaction.

100. Allergic effects are abnormal, toxic tissue disturbances and may be produced by any food constituent.

101. Decrease of an allergenic constituent may be accomplished by treatment or processing of the constituent.

102. When a food or ingredient is a plant or animal substance the allergenic property thereof is usually based on a specific factor, most frequently a protein, derivable only from the plant or animal which is its source.

103. Persons subject to gastrointestinal allergic effects can avoid them only by elimination of the allergenic substances from their diets or by such a reduction thereof that the quantity is insufficient to produce the toxic disturbances, and in some cases by hyposensitization measures.

104. Information necessary to inform the purchaser of the value of a food for hypoallergenic use includes the following: The common or usual name and the quantity or proportion of each ingredient, in case it is fabricated from two or more ingredients; a qualification of the name of the food, in case it consists of a single ingredient, or of the name of each ingredient, in case it is fabricated from two or more ingredients, to reveal the specific plant or animal which is the source of such food or such ingredient, if such food or such ingredient consists in whole or in part of plant or animal matter and such name does not clearly reveal the specific plant or animal which is such source; a statement indicating the nature and effect of any treatment or processing, if the changed allergenic property results from such treatment or processing.

On the basis of the foregoing detailed findings of fact it is found and determined that the label of a food which purports to be or is represented for special dietary uses by man should bear the information concerning the vitamin, mineral, and other dietary properties of such food prescribed in the regulations hereinafter set forth, and that such information concerning such properties of such food is necessary in order fully to inform purchasers as to its value for such uses.

It is therefore, ordered, That the following regulations be and they hereby are promulgated:

Regulations

Sec.

- 125.01 Definitions and interpretations of terms.
- 125.02 General label statements.
- 125.03 Label statements relating to vitamins.
- 125.04 Label statements relating to minerals.
- 125.05 Label statements relating to infant food.
- 125.06 Label statements relating to certain food used in control of body weight or in dietary management with respect to diseases.
- 125.07 Label statements relating to non-nutritive constituents.
- 125.08 Label statements relating to hypoallergenic food.

§ 125.01 *Definitions and interpretations of terms.* (a) The definitions and interpretations of terms contained in section 201 of the Act shall be applicable also to such terms when used in these regulations.

(b) Any requirement of the regulations in this part with respect to the quantity of vitamin A means the biologically measured activity of vitamin A and its precursors; but if any such precursor is sold as such or is added to a food the label shall designate such precursor by its common or usual name and not as vitamin A.

(c) Specification in the regulations in this part of a quantity of any vitamin, mineral, or other dietary property as a minimum daily requirement shall not be construed as a determination that such quantity is sufficient for the treatment of any disease resulting from a deficiency in such vitamin, mineral, or other property.

(d) For the purposes of the regulations in this part, the terms "infant", "child", and "adult" mean persons not more than 12 months old, more than 12 months but less than 12 years old, and 12 years or more old, respectively.*

§ 125.02 *General label statements.* (a) If a food (including food to which any one or more of the §§ 125.03 to 125.08, inclusive, of the regulations in this part is applicable) purports to be or is represented for any special dietary use by man, its label shall bear a statement of the dietary properties upon which such use is based in whole or in part. Such statement shall show the presence or absence of any substance, any alteration of the quantity or character of any constituent, and any other dietary property of such food upon which such use is so based.

(b) If a food (including food to which any one or more of §§ 125.03 to 125.08, inclusive, of the regulations in this part is applicable) purports to be or is represented for special dietary use by reason of its use for treating any disease resulting from a dietary deficiency in man, its label shall bear, in addition to the information required under paragraph (a) hereof, adequate directions for such use.*

§ 125.03 *Label statements relating to vitamins.* (a) (1) If a food purports to be or is represented for special dietary use by man by reason of its vitamin property in respect of—

Vitamin A or its precursors,
Vitamin B₁ (thiamine),
Vitamin C (ascorbic acid),
Vitamin D, or
Riboflavin (vitamin B₂, vitamin G),

the label (except as hereinafter provided with respect to cows' milk and evaporated milk, and unless the exemption under subparagraph (4) of this paragraph applies) shall bear a statement of the proportion of the minimum daily requirement for such vitamin supplied by such food when consumed in a specified quantity during a period of one day. If such purported or represented special dietary use is for persons within two or more age groups for which minimum daily requirements are set forth in paragraph (b), such statement shall include such proportion for each such group; but if such use is for persons irrespective of age groups, such statement may be limited to the proportion of the minimum daily requirement set forth in paragraph (b) for an adult. The quantity specified as above required shall be the quantity customarily or usually consumed during a period of one day, or a quantity reasonably suitable for and practicable of consumption within such period. When such proportion is a whole number and a fraction it may be expressed as the whole number and the fraction may

* §§ 125.01 to 125.08, inclusive, issued under the authority contained in secs. 403 (j), 701 (e), 52 Stat. 1048, 1055, 53 Stat. 561; 21 U.S.C., Sup. 343 (j), 371 (e), 5 U.S.C., Sup., 133-133t, and Reorganization plans I, IV, 53 Stat. 1423, 54 Stat. 1234; 4 F.R. 2727, 5 F.R. 2421.

be disregarded. The foregoing requirements of this paragraph shall not apply to cows' milk and evaporated milk which purport to be or are represented for special dietary use by reason of their content of vitamin D; but in the case of cows' milk in which the vitamin D content has been increased by any means, and in the case of evaporated milk with increased vitamin D content as prescribed in the definition and standard of identity for evaporated milk (§ 18.520), the label shall bear a statement of the number of U. S. P. units in a specified quantity of such milk or evaporated milk. In the case of cows' milk in which the vitamin D content is increased to less than 135 U. S. P. units to each quart, the label shall also bear a statement that additional vitamin D should be supplied from other sources.

(2) If a food purports to be or is represented for special dietary use by man by reason of its vitamin property in respect of any vitamin not listed in subparagraph (1) of this paragraph, the label shall bear a statement of the quantity of such vitamin in a specified quantity of such food. The quantity of food specified as required herein shall be the quantity customarily or usually consumed during a period of one day, or a quantity reasonably suitable for and practicable of consumption within such period. If the need in human nutrition for such vitamin has not been established, the label shall also bear the statement "The need for _____ in human nutrition has not been established," the blank to be filled in with the name of such vitamin.

(3) If a food purports to be or is represented for special dietary use by man by reason of its vitamin property, and any such use is for treating any disease resulting from a dietary deficiency of any vitamin, the label shall bear a statement of the quantity of such vitamin in a specified quantity of such food. If the represented special dietary use of such food is solely for treating any such disease, such food shall be exempt from the labeling requirements of subparagraphs (1) and (2) of this paragraph when otherwise applicable.

(4) Compliance with the provisions of subparagraphs (2) and (3) of this paragraph shall not be construed as relieving any food which purports to be or is represented for special dietary use by reason of its vitamin property from the application of sections 403 (a) and 201 (n) of the Act, as in the case where the need for such vitamin in human nutrition is not substantially supported by the opinion of experts qualified by scientific training and experience to determine such needs.

(b) For the purposes of the regulations in this section the following are minimum daily requirements:

(1) For vitamin A, 1,500 U. S. P. units for an infant, 3,000 U. S. P. units for a child, 4,000 U. S. P. units for an adult.

(2) For vitamin B₁ (thiamine), 0.25 milligram (83 U. S. P. units) for an infant, 0.5 milligram (167 U. S. P. units) for a child less than six years old, 0.75 milligram (250 U. S. P. units) for a child six or more years old, 1 milligram (333 U. S. P. units) for an adult.

(3) For vitamin C (ascorbic acid), 10 milligrams (200 U. S. P. units) for an infant, 20 milligrams (400 U. S. P. units) for a child, 30 milligrams (600 U. S. P. units) for an adult.

(4) For vitamin D, 400 U. S. P. units for an infant, child, or adult.

(5) For riboflavin (vitamin B₂, vitamin G), 0.5 milligram for an infant, 2.0 milligrams for an adult.*

§ 125.04 *Label statements relating to minerals.* (a) (1) If a food purports to be or is represented for special dietary use by man by reason of its mineral property in respect of Calcium, Phosphorus, Iron, or Iodine, the label (except as hereinafter provided with respect to iodized salt, and unless the exemption under subparagraph (4) of this paragraph applies) shall bear a statement of the proportion of the minimum daily requirement for such element supplied by such food when consumed in a spec-

ified quantity during a period of one day. If such purported or represented special dietary use is for persons within two or more age groups or other groups having special dietary requirements, for which minimum daily requirements are set forth in paragraph (b), such statement shall include such proportion for each such group; but if such use is for persons irrespective of such groups, such statement may be limited to the proportion of the minimum daily requirement set forth in paragraph (b) for an adult other than a pregnant or lactating woman. The quantity specified as above required shall be the quantity customarily or usually consumed during a period of one day, or a quantity reasonably suitable for and practicable of consumption within such period. When such proportion is a whole number and a fraction it may be expressed as the whole number and the fraction may be disregarded. The foregoing requirements of this paragraph shall not apply to iodized salt which purports to be or is represented for special dietary use by reason of its iodine content, if the label bears a statement of the quantity or proportion of iodine, or salt thereof, in the iodized salt and the quantity of iodine present therein is not more than 0.02 percent by weight.

(2) If a food purports to be or is represented for special dietary use by man by reason of its mineral property in respect of any element not listed in subparagraph (1) of this paragraph, the label shall bear a statement of the quantity of such element in a specified quantity of such food. The quantity of food specified as required herein shall be the quantity customarily or usually consumed during a period of one day, or a quantity reasonably suitable for and practicable of consumption within such period. If the need in human nutrition for such element has not been established, the label shall also bear the statement "The need for _____ in human nutrition has not been established," the blank to be filled in with the name of such element.

(3) If a food purports to be or is represented for special dietary use by man by reason of its mineral property, and any such use is for treating any disease resulting from a dietary deficiency of any element, the label shall bear a statement of the quantity of such element in a specified quantity of such food. If the represented special dietary use of such food is solely for treating any such disease, such food shall be exempt from the labeling requirements of subparagraphs (1) and (2) of this paragraph when otherwise applicable.

(4) Compliance with the provisions of subparagraphs (2) and (3) of this paragraph shall not be construed as relieving any food which purports to be or is represented for special dietary use by reason of its mineral property from the application of §§ 403 (a) and 201 (n) of the Act, as in the case where the need for such element in human nutrition is not substantially supported by the opinion of experts qualified by scientific training and experience to determine such needs.

(b) For the purposes of the regulations in this section, the following are minimum daily requirements:

(1) For calcium (Ca), 750 milligrams for a child or an adult, except a pregnant or lactating woman in which case the minimum daily requirement is 1.5 grams.

(2) For phosphorus (P), 750 milligrams for a child or an adult, except a pregnant or lactating woman in which case the minimum daily requirement is 1.5 grams.

(3) For iron (Fe), 7.5 milligrams for a child less than six years old, 10 milligrams for a child six or more years old or for an adult, except a pregnant or lactating woman in which case the minimum daily requirement is 15 milligrams.

(4) For iodine (I), 0.1 milligram for a child or an adult.*

§ 125.05 *Label statements relating to infant food.* If a food which purports to be or is represented for special dietary use is a food for infants, the label shall bear, in case such food is fabricated from two or more ingredients, the common or usual name of each such ingredient, including spice, flavoring, and coloring; if such food, or any

ingredient thereof in case it is fabricated from two or more ingredients, consists in whole or in part of plant or animal matter and the name of such food or ingredient does not clearly reveal the specific plant or animal which is its source, such name shall be so qualified as to reveal clearly the specific plant or animal which is such source. If such use of the food is by reason of its simulation of human milk or its suitability as a complete or partial substitute for human milk, the label shall also bear.

(a) a statement of the percent by weight of moisture, protein, fat, available carbohydrate, crude fiber, calcium (Ca), phosphorus (P), and iron (Fe) contained in such food;

(b) a statement of the number of available calories and of U. S. P. units of vitamin A, vitamin B₁ (thiamine), vitamin C (ascorbic acid), and vitamin D supplied by a specified quantity of such food; and

(c) If less than 30 U. S. P. units of vitamin C (ascorbic acid), less than 50 U. S. P. units of vitamin D, or less than 0.75 milligram of iron (Fe), is supplied by the quantity of such food which, as customarily or usually prepared for consumption, supplies 100 available calories, a statement that additional quantities of such vitamin or iron, as the case may be, should be supplied from other sources.

The provisions of paragraphs (a) and (b) of this section shall not apply to cows' milk and evaporated milk. The provisions of paragraph (c) of this section with respect to vitamin D shall not apply to cows' milk or evaporated milk in which the vitamin D is increased by any means to not less than 135 U. S. P. units to each quart in the case of cows' milk and not less than 7.5 U. S. P. units to each avoirdupois ounce in the case of evaporated milk.*

§ 125.06 *Label statements relating to certain food used in control of body weight or in dietary management with respect to disease.* If a food purports to be or is represented for special dietary use by man by reason of its use as a means of regulating the intake of protein, fat, carbohydrate, or calories, for the purpose of controlling body weight or for the purpose of dietary management with respect to disease, the label shall bear a statement of—

(a) the percent by weight of protein; fat, and available carbohydrates in such food; and

(b) the number of available calories supplied by a specified quantity of such food.*

§ 125.07 *Label statements relating to nonnutritive constituents.* If a food purports to be or is represented for special dietary use by man by reason of the presence of any constituent which is not utilized in normal metabolism, the label shall bear a statement of the percent by weight of such constituent, and, in juxtaposition with the name of such constituent, the word "nonnutritive". If such constituent is fibrous plant matter, it shall be considered to be crude fiber and its percent expressed as such. But if such constituent is saccharin or a saccharin salt, the label shall bear, in lieu of such statement and word, the statement "Contains_____saccharin (or saccharin salt, as the case may be), a non-nutritive,¹ artificial sweetener which should be used only by persons who must restrict their intake of ordinary sweets", the blank to be filled in with the percent by weight of saccharin or saccharin salt in such food. The provisions of this section shall not be construed as authorizing the use of saccharin or its salts in any food other than one for use by persons who must restrict their intake of carbohydrates, or as relieving any food from compliance with any requirement of sections 402 (b) or (d), 403 (g), or other provisions of the Act.*

§ 125.08 *Label statements relating to hypoallergenic food.* If a food purports to be or is represented for special dietary use by man by reason of the decrease or absence of any allergenic property, the label shall bear

(a) the common or usual name and the quantity or proportion of each ingredient including spices, flavoring, and coloring, in case the food is fabricated from two or more ingredients;

(b) a qualification of the name of the food, or of the name of each ingredient thereof in case the food is fabricated from two or more ingredients, to reveal clearly the specific plant or animal which is the source of such food or of such ingredient, if such food or such ingredient consists in whole or in part of plant or animal matter and such name does not clearly reveal the specific plant or animal which is such source; and

(c) a statement indicating the nature and effect of any treatment or processing of the food or any ingredient thereof, if the changed allergenic property results from such treatment or processing.*

These regulations shall be effective from and after the 180th day from this day.

WATSON B. MILLER,
Acting Administrator.

NOVEMBER 18, 1941.

D. LABEL DECLARATION OF SALT IN FROZEN VEGETABLES

Pursuant to section 3 of the Administrative Procedure Act (60 Stat. 237, 238; 5 U.S.C. 1002), the following statement of policy is issued:

§ 3.31 *Label declaration of salt in frozen vegetables.* (a) In a number of diseases or disease conditions it is important to restrict the intake of sodium. Sodium occurs in all natural foods, but added salt makes the most important contribution to the total sodium intake in the diet. Most fresh vegetables are of low sodium content and consumers generally regard frozen vegetables as being free of added salt and suitable for use in low-sodium diets. While salt may not be added directly as a seasoning ingredient during the processing of frozen vegetables, the use of salt brine in quality separation of such vegetables as peas and lima beans preparatory to freezing may contribute substantial amounts of salt to the finished article. The failure of the labels of frozen vegetables to declare the presence of salt has been the basis of complaints to the Food and Drug Administration.

(b) Section 403 (i) (2) of the Federal Food, Drug, and Cosmetic Act requires the label of a fabricated food to bear the common or usual name of each ingredient present. The Department of Health, Education, and Welfare regards any frozen vegetable containing salt, added directly or indirectly, as misbranded in violation of section 403 (i) (2) of the Federal Food, Drug, and Cosmetic Act unless its label names salt as an ingredient.

((Sec. 701, 52 Stat. 1055; 21 U.S.C. 371. Interpret or apply sec. 403 (i) (2), 52 Stat. 1048; 21 U.S.C. 343 (i) (2))

NOVEMBER 9, 1953.

OVETA CULP HOBBY,
Secretary.

(Published in Federal Register November 14, 1953, 18 F.R.7232)

E. LABEL STATEMENTS CONCERNING DIETARY PROPERTIES OF FOOD PURPORTING TO BE OR REPRESENTED FOR SPECIAL DIETARY USES

NOTICE OF PROPOSED RULE MAKING

In the matter of amending the regulations pertaining to label statements concerning dietary properties of food purporting to be or represented for special dietary uses:

It is proposed that, by virtue of the authority vested in the Secretary of Health, Education, and Welfare by the provisions of the Federal Food, Drug, and Cosmetic Act (secs. 403 (j), 701, 52 Stat. 1048, 1055; 21 U.S.C. 343 (j), 371; 67 Stat. 18) and upon the basis of substantial evidence received at the public hearing held pursuant to the notice published in the *FEDERAL REGISTER* on November 14, 1953 (18 F.R. 7249), the following order be made:

*Findings of fact.*¹ 1. Sodium-restricted diets have come to be widely used in medical practice within recent years. Such diets are used in dietary management in the treatment of the edema associated with some types of heart, liver, and kidney disease; for the prevention of the recurrence of such edema; and in the treatment of essential hypertension. Persons may be on sodium-restricted diets for a short period of time or over a period of years. The persons on such diets may be hospitalized or at home. (R. 105-106, 110-111, 118-119, 127-130, 148-149, 152-155, 170, 180; Ex. 21, 26, 27, 27-A, 27-B)

2. Sodium-restricted diets are formulated on the basis of the total amount of sodium permitted each day. The level of the restriction is stated in terms of milligrams or grams per day. The level of restriction depends upon the individual, his disease, and his response to treatment. Restrictions may be mild, moderate, or severe. Diets furnishing materially less than 500 milligrams of sodium daily may be prescribed in severe restriction. (R. 106-108, 149, 163-164, 170, 182-183, 185, 187; Ex. 21, 26, 27, 27-A, 27-B)

3. In sodium-restricted diets the total sodium content of the food consumed is of importance, whether derived from added salt (sodium chloride) or from sodium natural to the food, or added to the food by ingredients other than salt used in the food processing or manufacturing. (R. 108-110, 149-151, 171-172, 181, 185; Ex. 21, 26, 27, 27-A, 27-B)

4. While added salt (sodium chloride) is the main source of sodium in the diet, the total quantity of sodium in food is also influenced by the natural sodium content of the food and by ingredients other than salt used in food processing or manufacturing. Baking powder, monosodium glutamate, baking soda, sodium alginate, and water are examples of materials used in food processing or manufacturing that contribute to the sodium content of the foods in which they are used. (R. 52, 74-77, 109-110, 181, 185, 206; Ex. 21, 22, 24, 26, 27, 27-A, 27-B)

5. Among the persons choosing foods for use in a sodium-restricted diet are patients under the care of a physician, members of the families of such patients who have charge of preparing foods in the home, and, in the case of hospital diets, dietitians or similarly trained persons in the hospital. Among the foods offered for use in sodium-restricted diets are natural and prepared foods normally low in sodium and specially prepared foods in which the normal sodium content has been reduced. Certain prepared foods, which normally are seasoned with salt, may be prepared without such seasoning. There are now on the market various commercially prepared foods designed to supply the need of persons selecting foods for sodium-restricted diets. Such foods are commonly labeled to call attention to their sodium content. This includes statements such as "salt free," "no added salt," "low sodium," "sodium free," and the like. Where the sodium content is declared, the declaration is commonly in terms of milligrams of sodium in 100 grams of the food, or in terms of percentage, or in terms of milligrams of sodium in a specified serving. (R. 21-28, 35-37, 114, 149, 185-187; Ex. 10-12, 20-22, 26, 27, 27-A)

¹ The citations following each finding of fact refer to the pages of the transcript of the testimony and the exhibits received in evidence at the hearing.

6. Products that are labeled "packed without added salt," "salt free," "low sodium," and the like, without quantitative declaration of sodium content, are often represented for use in sodium-restricted diets by firms marketing such foods. Whether or not other representations are made by firms marketing such foods, products so labeled are considered by physicians, nutritionists, dietitians, and consumers as foods represented to be suitable for use in sodium-restricted diets. Products so labeled may or may not be of low-sodium content. (R. 6-19, 51, 53, 64-77, 112-114, 150-151, 181, 187, 197; Ex. 2-A-9, 22-24, 27)

7. Physicians, nutritionists, dietitians, and many consumers have become accustomed to evaluating the sodium content of foods in terms of milligrams of sodium in 100 grams of the food, and the published values for the sodium content of food for sodium-restricted diets are generally in terms of milligrams of sodium in 100 grams of the food. Physicians and dietitians, on the basis of available information of sodium content of foods, give instructions in the selection of suitable foods to patients who must restrict their sodium intake. (R. 111-118, 143, 183-184; Ex. 21, 26, 72)

8. To meet the needs of persons who purchase foods for use in sodium-restricted diets, the foods offered for this purpose should be labeled in terms of the number of milligrams of sodium in 100 grams of the food. In addition to the statement of the number of milligrams of sodium in 100 grams of the food, the purchaser needs information concerning the amount of sodium in an average serving of the food. The amount of food in an average serving should be expressed in terms of the number of fixed portions such as slices, cookies, wafers, etc., ordinarily consumed or in terms of convenient units of measure such as cupfuls, tablespoonfuls, teaspoonfuls, etc., which may be readily understood and utilized by purchasers of such food. (R. 53, 55-57, 113-115, 135-136, 143-144, 151-152, 171-172, 185, 189-190; Ex. 21, 26, 27, 27-A, 27-B)

9. Reliable and practicable methods are available for the determination of the sodium content of foods, and some packers of foods are currently using such methods in determining the sodium content of their low-sodium foods. (R. 29-42, 48-50, 58-101; Ex. 13-19, 21)

Conclusions. Upon consideration of the whole record and the foregoing findings of fact, it is concluded that the label for a food that purports to be or is represented for special dietary use by man as a means of regulating the intake of sodium in dietary management should bear the information concerning its sodium content as specified in the amended regulations hereinafter set forth, and that such information is necessary in order fully to inform purchasers as to the value of the food for such uses.

1. In § 125.4 *Label statements relating to minerals*, it is proposed to amend paragraph (a) (2) by changing the second sentence to read as follows: "Except in the case of foods subject to § 125.9, the quantity of food specified as required in this section shall be the quantity customarily or usually consumed during a period of one day, or a quantity reasonably suitable for and practicable of consumption within such period."

2. It is proposed to amend Part 125 by adding the following new section:

§ 125.9 *Label statements relating to certain foods used as a means of regulating the intake of sodium in dietary management.* If a food purports to be or is represented for special dietary use by man by reason of its use as a means of regulating the intake of sodium or salt (sodium chloride), the label shall bear a statement of the number of milligrams of sodium in 100 grams of the food and a statement of the number of milligrams of sodium in an average serving of the food. The average serving shall be expressed in terms of a convenient unit or units of such food or a convenient unit of measure that can be readily understood and utilized by purchasers of such food.

For example, an average serving might be expressed in terms of a number of slices, cookies, wafers, etc., or in terms of cupfuls, tablespoonfuls, teaspoonfuls, etc.

Any interested person whose appearance was filed at the hearing may, within 30 days from the date of publication of this tentative order in the *FEDERAL REGISTER*, file with the Hearing Clerk, Department of Health, Education, and Welfare, Room 5440, Health, Education, and Welfare Building, Fourth Street and Independence Avenue SW, Washington 25, D. C., written exceptions thereto. Exceptions shall point out with particularity the alleged errors in this tentative order and shall contain specific references to the pages of the transcript of the testimony or to the exhibits on which such exceptions are based. Such exceptions may be accompanied by a memorandum or brief in support thereof. Exceptions and accompanying memoranda or briefs shall be submitted in quintuplicate.

MAY 7, 1954.

OVETA CULP HOBBY
Secretary.

(Published in Federal Register May 13, 1954; 19 F.R. 2767)

F. LABEL DECLARATIONS OF VITAMIN B₁₂ AND FOLIC ACID IN FOODS FOR SPECIAL DIETARY USES

Pursuant to section 3 of the Administrative Procedure Act (sec. 3, 60 Stat. 237, 238; 5 U.S.C. 1002), the following statement of policy is issued:

§3.32 *Label declarations of vitamin B₁₂ and folic acid in foods for special dietary uses.*

(a) Section 125.3 (a) (2) of this chapter, issued under the authority of section 403 (j) of the Federal Food, Drug, and Cosmetic Act (sec. 403 (j), 52 Stat. 1048; 21 U.S.C. 343 (j)) requires that if a food purports to be or is represented for special dietary use by man by reason, in whole or in part, of a vitamin for which the need in human nutrition has not been established, the label of such food shall bear the statement "The need for _____ in human nutrition has not been established," the blank to be filled in with the name of such vitamin.

(b) Heretofore this Department has considered vitamin B₁₂ and folic acid as among those vitamins for which the need in human nutrition has not been established. However, recent scientific evidence shows that these vitamins are needed in human nutrition. The Department therefore considers the requirement of §125.3 (a) (2) quoted in paragraph (a) of this section as no longer applicable to food offered for special dietary use by reason of these vitamins.

(Sec. 701, 52 Stat. 1055; 21 U.S.C. 371. Interpret or apply sec. 403 (j), 52 Stat. 1048; 21 U.S.C. 343 (j))

FEBRUARY 4, 1954

OVETA CULP HOBBY
Secretary.

(Published in Federal Register February 10, 1954; 19 F.R. 767)

G. PESTICIDE REGULATIONS

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

Food and Drug Administration

Proposed regulations to establish safe limits, or to prohibit pesticide chemical residues on fresh fruits and vegetables were announced on Oct. 20, 1954 by the U. S. Department of Health, Education, and Welfare. The regulations cover pesticides ranging from those which are virtually harmless to some which are among the most potent poisons known.

The proposed regulations are in two parts, both appearing in the Federal Register for Oct. 20, 1954, vol. 19, #204.

The first regulation proposes tolerances for 26 pesticides in common use, based on scientific data developed at hearings held in 1950 under section 406 of the Federal Food, Drug, and Cosmetic Act. Sixty days are allowed for parties who appeared at the hearings to file exceptions to this proposal.

The second regulation sets up the operating procedure under the new Miller pesticide chemicals amendment (Public Law 518) which President Eisenhower signed into law on July 22, 1954. Sixty days are allowed for interested persons to submit their views in writing and to request a hearing if desired.

The table gives the names of pesticides for which proposed tolerances have been set, the amount of the tolerances, and the food crops to which each applies. Under the proposed regulations any of the listed fruits and vegetables could legally be distributed in interstate commerce if it does not carry more than the specified tolerance of a permitted pesticide. But combinations of pesticide residues with related pharmacologic effects are limited so that the total amount of combined residues will be safe.

The proposed regulations provide that no residues of the following pesticides shall remain on fruits or vegetables (i.e., that these pesticides shall have a tolerance of zero):

- Calcium cyanide
- Dinitro-*O*-sec. butylphenol
- Dinitro-*O*-cresol
- Hexaethyl tetraphosphate (HETP)
- Tetraethyl pyrophosphate (TEPP)
- Hydrocyanic acid
- Mercury-containing compounds
- Nicotine and nicotine-containing materials
- Selenium and selenium-containing compounds

Some of these compounds, calcium cyanide and hydrocyanic acid, for example, are applied to crops at such time in their growth, or are dissipated so rapidly after application that a zero tolerance will have little or no effect upon the manner in which they are employed in agriculture.

Others, such as the mercury and selenium compounds, if employed at all, must be used with unusual care to keep the finished crop from bearing any residues when marketed.

The tolerances based on the 1950 hearings do not take into account technological and research advances made since that time but are subject to change under the procedure of the new amendment. New scientific data relating to the safety of any pesticide could be filed in the form of an application for a new tolerance. In a number of cases the evidence received in the 1950 hearings was not sufficient to permit the establishment of a satisfactory tolerance. Applications to establish tolerances for these pesticides, and for any new pesticide chemicals, or to revise existing tolerances, would also be processed under the new Miller amendment. Zero tolerances would be set whenever it is found that any amount of residues of a pesticide, however small, would be unsafe for consumers, or where there was insufficient data to establish safety.

The proposed regulations under the new law would:

1. Set up exemptions for a group of common pesticides which are entirely safe when properly used on growing crops. These are: common copper compounds (except those containing arsenic); petroleum oils; pyrethrum, rotenone, and four synergists used to enhance their effects; ryania, and sabadilla. The latter two, like pyrethrum and rotenone, are insecticides derived from plants. The exemptions do not apply when this group of materials is used at time of harvest or after harvest.

2. Establish operating procedures and fees to make administration of the new law self-supporting. The proposed application fee for a new tolerance is \$500 and for extending a tolerance to additional crops, \$140.

3. Set up procedure for the appointment by the Department of experts selected by the National Academy of Science to committees to advise the Department in regard to controversial scientific questions arising in the establishment of tolerances. The cost of an advisory committee would be paid by the person requesting that it be appointed.

Under the new law the Secretary of Agriculture is required to certify whether a pesticide chemical is useful in agricultural production before the Secretary of Health, Education, and Welfare is required to act upon a petition to set up a tolerance for that chemical. All economic poisons (pesticide chemicals) which move interstate must be registered by the U. S. Department of Agriculture under the Federal Insecticide, Fungicide, and Rodenticide Act of 1947 and labeled according to that law. The new Miller amendment to the Federal Food, Drug, and Cosmetic Act makes the Secretary of Health, Education, and Welfare responsible for protecting the public health from foods exposed to dangerous amounts of pesticide chemicals.

H. TOLERANCES

Established under Sec. 406, Federal Food, Drug, and Cosmetic Act

Pesticide	Tolerance in ppm	Fruits and vegetables to which tolerance applies
Aldrin	0.1	Potatoes, sweet potatoes
Benzene hexachloride	5	Apples, pears, quinces, apricots, avocados, cherries, citrus fruits, grapes, guavas, mangoes, peaches, nectarines, pineapples, plums, strawberries, asparagus, beans, black-eyed peas, broccoli, cabbage, brussels sprouts, kohlrabi, cauliflower, corn, eggplants, kale, collards, lettuce, mustard greens, okra, onions, peas, peppers, spinach, Swiss chard, tomatoes
Calcium arsenate	3.5 of combined As_2O_3	Blueberries (huckleberries), raspberries, blackberries, loganberries, strawberries, asparagus, beans, black-eyed peas, broccoli, cabbage, brussels sprouts, kohlrabi, cauliflower, carrots, celery, corn, cucumbers, eggplants, kale, collards, melons, peppers, pumpkins, spinach, squash, tomatoes, turnips
Copper arsenate	3.5 of combined As_2O_3	Cabbage, brussels sprouts, kohlrabi, cauliflower, carrots, tomatoes
DDT	7	Apples, pears, quinces, apricots, avocados, blueberries (huckleberries), cherries, citrus fruits, cranberries, currants, gooseberries, grapes, guavas, mangoes, papayas, peaches, nectarines, pineapples, plums, raspberries, blackberries, loganberries, rhubarb, strawberries, artichokes, asparagus, beans, black-eyed peas, beets, broccoli, cabbage, brussels sprouts, kohlrabi, cauliflower, carrots, celery, corn, cucum-

TOLERANCES (*continued*)

Pesticide	Tolerance in ppm	Fruits and vegetables to which tolerance applies
		bers, eggplants, endive, kale, collards, lettuce, melons, mushrooms, mustard greens, okra, onions, parsnips, peanuts, peas, peppers, pumpkins, radishes, rutabagas, spinach, squash, tomatoes, turnips
Chlordane or heptachlor	0.1	Potatoes
2,4-Dichloro-phenoxy acetic acid	5	Apples, pears, quinces, citrus fruits
Dicyclohexylamine salt of dinitro-O-hexylphenol	1	Apples, pears, quinces, apricots, cherries, grapes, peaches, nectarines, plums, raspberries, blackberries, loganberries, strawberries, beans, black-eyed peas, celery
Dieldrin	0.1	Apples, pears, quinces, apricots, cherries, peaches, nectarines, onions
EPN	3	Apples, pears, quinces, apricots, cherries, citrus fruits, peaches, nectarines, pineapples, plums, raspberries, blackberries, loganberries, strawberries, corn, lettuce, spinach, turnips, beans, black-eyed peas, beets
Forbam	7	Apples, pears, quinces, apricots, blueberries (huckleberries), cherries, cranberries, currants, dates, gooseberries, grapes, guavas, mangoes, papayas, peaches, nectarines, plums, raspberries, blackberries, loganberries, beans, black-eyed peas, beets, broccoli, cabbage, brussels sprouts, kohlrabi, cauliflower, collards, carrots, celery, cucumbers, eggplants, kale, lettuce, melons, mustard greens, onions, peanuts, peas, peppers, pumpkins, radishes, squash, tomatoes, turnips
Fluorine compounds	7 of combined fluorine	Apples, pears, quinces, apricots, blueberries (huckleberries), citrus fruits, cranberries, grapes, peaches, nectarines, plums, raspberries, blackberries, loganberries, strawberries, beans, black-eyed peas, beets, broccoli, cabbage, brussels sprouts, kohlrabi, cauliflower, carrots, corn, cucumbers, eggplants, kale, collards, lettuce, melons, mustard greens, okra, peanuts, peas, peppers, pumpkins, radishes, squash, tomatoes, turnips
2-Heptadecyl glyoxalidine	5	Apples, pears, quinces, cherries, raspberries, blackberries, loganberries
Lead arsenate	7 of combined lead	Apples, pears, quinces, apricots, blueberries (huckleberries), cherries, cranberries, currants, gooseberries, grapes, mangoes, peaches, nectarines, strawberries, asparagus, celery, eggplants, peppers, tomatoes, avocados

TOLERANCES (*continued*)

Pesticide	Tolerance in ppm	Fruits and vegetables to which tolerance applies
Lead arsenate	1.0 of combined lead	Citrus fruits (grapefruit, lemons, oranges, tangerines)
Magnesium arsenate	3.5 of combined As_2O_3	Beans, black-eyed peas
Methoxychlor	14	Apples, pears, quinces, apricots, cherries, cranberries, grapes, peaches, nectarines, pineapples, raspberries, blackberries, loganberries, strawberries, asparagus, beans, black-eyed peas, beets, broccoli, cabbage, brussels sprouts, kohlrabi, cauliflower, corn, cucumbers, eggplants, kale, collards, lettuce, melons, mushrooms, peas, peppers, pumpkins, radishes, squash, tomatoes, turnips
Naphthalene acetic acid	1	Apples, pears, quinces
Parathion	1	Apples, pears, quinces, apricots, avocados, cherries, citrus fruits, currants, dates, figs, gooseberries, grapes, guavas, mangoes, peaches, nectarines, pineapples, raspberries, blackberries, loganberries, strawberries, artichokes, beans, black-eyed peas, beets, broccoli, cabbage, brussels sprouts, kohlrabi, cauliflower, carrots, celery, corn, cucumbers, eggplants, kale, collards, mellons, mustard greens, okra, parsnips, peas, peppers, pumpkins, radishes, spinach, squash, Swiss chard, tomatoes, turnips
Phenothiazine	7	Apples, pears, quinces
Sodium arsenate	3.5 of combined As_2O_3	Grapes
Tartar emetic	3.5 of combined antimony trioxide	Citrus fruits, grapes, onions
TDE	7	Apples, pears, quinces, apricots, cherries, citrus fruits, grapes, peaches, nectarines, raspberries, blackberries, loganberries, strawberries, beans, black-eyed peas, broccoli, cabbage, brussels sprouts, kohlrabi, cauliflower, carrots, corn, eggplants, peas, peppers, spinach, tomatoes
Toxaphene	7	Apples, pears, quinces, apricots, citrus fruits, peaches, nectarines, raspberries, blackberries, loganberries, strawberries, beans, black-eyed peas, broccoli, cabbage, brussels sprouts, kohlrabi, cauliflower, carrots, celery, corn, cucumbers, eggplants, lettuce, okra, onions, parships, peas, radishes, tomatoes
Zineb	7	Apples, pears, quinces, cherries, cranberries, gooseberries, grapes, peaches, nectarines, raspberries, blackberries, loganberries, strawberries, beans, black-eyed peas, beets, broccoli,

TOLERANCES (*continued*)

Pesticide	Tolerance in ppm	Fruits and vegetables to which tolerance applies
Ziram	7	cabbage, brussels sprouts, kohlrabi, cauliflower, carrots, celery, cucumbers, eggplants, endive, escarole, kale, collards, lettuce, melons, mushrooms, onions, parsley, peanuts, peas, peppers, pumpkins, radishes, salsify, squash, Swiss chard, tomatoes, turnips Apples, pears, quinces, apricots, blueberries (huckleberries), cherries, cranberries, gooseberries, grapes, peaches, nectarines, raspberries, blackberries, loganberries, beans, black-eyed peas, beets, broccoli, cabbage, brussels sprouts, kohlrabi, cauliflower, carrots, celery, cucumbers, eggplants, kale, collards, lettuce, melons, onions, parsnips, peas, peppers, pumpkins, radishes, squash, tomatoes, turnips

2. THE FEDERAL MEAT INSPECTION ACT

Extract from an act of Congress entitled "An act making appropriations for the Department of Agriculture for the fiscal year ending June thirtieth, nineteen hundred and seven," approved June 30, 1906 (34 Stat. 674), and from an act of Congress entitled "An act making appropriations for the Department of Agriculture for the fiscal year ending June thirtieth, nineteen hundred and eight," approved March 4, 1907 (34 Stat. 1260).

[1] That [hereafter,]¹ for the purpose of preventing the use in interstate or foreign commerce, as hereinafter provided, of meat and meat food products which are unsound, unhealthful, unwholesome, or otherwise unfit for human food, the Secretary of Agriculture, at his discretion, may cause to be made, by inspectors appointed for that purpose, an examination and inspection of all cattle, sheep, swine, and goats before they shall be allowed to enter into any slaughtering, packing, meat-canning, rendering, or similar establishment, in which they are to be slaughtered and the meat and meat food products thereof are to be used in interstate or foreign commerce; and all cattle, swine, sheep, and goats found on such inspection to show symptoms of disease shall be set apart and slaughtered separately from all other cattle, sheep, swine, or goats, and when so slaughtered, the carcass of said cattle, sheep, swine, or goats shall be subject to a careful examination and inspection, all as provided by the rules and regulations to be prescribed by the Secretary of Agriculture as herein provided for.

[2] That for the purposes hereinbefore set forth the Secretary of Agriculture shall cause to be made by inspectors appointed for that purpose, as hereinafter provided, a post-mortem examination and inspection of the carcasses and parts thereof of all cattle, sheep, swine, and goats to be prepared for human consumption at any slaughtering, meat-canning, salting, packing, rendering, or similar establishment in any State, Territory, or the District of Columbia for transportation or sale as articles of interstate or foreign commerce; and the carcasses and parts thereof of all such animals found to be sound, healthful, wholesome, and fit for human food shall be marked, stamped, tagged, or labeled as "Inspected and Passed;" and said inspectors

¹ The word "hereafter" is used in the act of 1907 but not in that of 1906. With this exception and the amendment to the Act noted in footnote 2, the extract here given is identical in both laws.

shall label, mark, stamp, or tag as "Inspected and Condemned," all carcasses and parts thereof of animals found to be unsound, unhealthful, unwholesome, or otherwise unfit for human food; and all carcasses and parts thereof thus inspected and condemned shall be destroyed for food purposes by the said establishment in the presence of an inspector, and the Secretary of Agriculture may remove inspectors from any such establishment which fails to so destroy any such condemned carcasses or part thereof, and said inspectors, after said first inspection shall, when they deem it necessary, reinspect said carcasses or parts thereof to determine whether since the first inspection the same have become unsound, unhealthful, unwholesome, or in any way unfit for human food, and if any carcass or any part thereof shall, upon examination and inspection subsequent to the first examination and inspection, be found to be unsound, unhealthful, unwholesome, or otherwise unfit for human food, it shall be destroyed for food purposes by the said establishment in the presence of an inspector, and the Secretary of Agriculture may remove inspectors from any establishment which fails to so destroy any such condemned carcass or part thereof.

[3] The foregoing provisions shall apply to all carcasses or parts of carcasses of cattle, sheep, swine, and goats, or the meat or meat products thereof which may be brought into any slaughtering, meat-canning, salting, packing, rendering, or similar establishment, and such examination and inspection shall be had before the said carcasses or parts thereof shall be allowed to enter into any department wherein the same are to be treated and prepared for meat food products; and the foregoing provisions shall also apply to all such products which, after having been issued from any slaughtering, meat-canning, salting, packing, rendering, or similar establishment, shall be returned to the same or to any similar establishment where such inspection is maintained.

[4] That for the purposes hereinbefore set forth the Secretary of Agriculture shall cause to be made by inspectors appointed for that purpose an examination and inspection of all meat food products prepared for interstate or foreign commerce in any slaughtering, meat-canning, salting, packing, rendering, or similar establishment, and for the purposes of any examination and inspection said inspectors shall have access at all times, by day or night, whether the establishment be operated or not, to every part of said establishment; and said inspectors shall mark, stamp, tag, or label as "Inspected and Passed" all such products found to be sound, healthful, and wholesome, and which contain no dyes, chemicals, preservatives, or ingredients which render such meat or meat food products unsound, unhealthful, unwholesome, or unfit for human food; and said inspectors shall label, mark, stamp, or tag as "Inspected and Condemned" all such products found unsound, unhealthful, and unwholesome, or which contain dyes, chemicals, preservatives, or ingredients which render such meat or meat food products unsound, unhealthful, unwholesome, or unfit for human food, and all such condemned meat food products shall be destroyed for food purposes, as hereinbefore provided, and the Secretary of Agriculture may remove inspectors from any establishment which fails to so destroy such condemned meat food products: *Provided*, That, subject to the rules and regulations of the Secretary of Agriculture, the provisions hereof in regard to preservatives shall not apply to meat food products for export to any foreign country and which are prepared or packed according to the specifications or directions of the foreign purchaser, when no substance is used in the preparation or packing thereof in conflict with the laws of the foreign country to which said article is to be exported; but if said article shall be in fact sold or offered for sale for domestic use or consumption, then this proviso shall not exempt said article from the operation of all the other provisions of this act.

[5] That when any meat or meat food product prepared for interstate or foreign commerce which has been inspected as hereinbefore provided and marked "Inspected and Passed" shall be placed or packed in any can, pot, tin, canvas, or other receptacle or covering in any establishment where inspection under the provisions of this act is maintained, the person, firm, or corporation preparing said product shall cause a label to be attached to said can, pot, tin, canvas, or other receptacle or covering, under the supervision of an inspector, which label shall state that the contents thereof have been "Inspected and Passed" under the provisions of this act; and no inspection and examination of meat or meat food products deposited or inclosed in cans, tins, pots, canvas, or other receptacle or covering in any establishment where inspection under the provisions of this act is maintained shall be deemed to be complete until such meat or meat food products have been sealed or inclosed in said can, tin, pot, canvas, or other receptacle or covering under the supervision of an inspector, and no such meat or meat food products shall be sold or offered for sale by any person, firm, or corporation in interstate or foreign commerce under any false or deceptive name; but established trade name or names which are usual to such products and which are not false and deceptive and which shall be approved by the Secretary of Agriculture are permitted.

[6] The Secretary of Agriculture shall cause to be made, by experts in sanitation or by other competent inspectors, such inspection of all slaughtering, meat-canning, salting, packing, rendering, or similar establishments in which cattle, sheep, swine, and goats are slaughtered and the meat and meat food products thereof are prepared for interstate or foreign commerce as may be necessary to inform himself concerning the sanitary conditions of the same, and to prescribe the rules and regulations of sanitation under which such establishments shall be maintained; and where the sanitary conditions of any such establishment are such that the meat or meat food products are rendered unclean, unsound, unhealthful, unwholesome, or otherwise unfit for human food, he shall refuse to allow said meat or meat food products to be labeled, marked, stamped, or tagged as "Inspected and Passed."

[7] That the Secretary of Agriculture shall cause an examination and inspection of all cattle, sheep, swine, and goats, and the food products thereof, slaughtered and prepared in the establishments hereinbefore described for the purposes of interstate or foreign commerce to be made during the nighttime as well as during the daytime when the slaughtering of said cattle, sheep, swine, and goats, or the preparation of said food products is conducted during the nighttime.

[8] That on and after October first, nineteen hundred and six, no person, firm, or corporation shall transport or offer for transportation, and no carrier of interstate or foreign commerce shall transport or receive for transportation from one State or Territory or the District of Columbia to any other State or Territory or the District of Columbia, or to any place under the jurisdiction of the United States, or to any foreign country, any carcasses or parts thereof, meat, or meat food products thereof which have not been inspected, examined, and marked as "Inspected and Passed," in accordance with the terms of this act and with the rules and regulations prescribed by the Secretary of Agriculture: *Provided*, That all meat and meat food products on hand on October first, nineteen hundred and six, at establishments where inspection has not been maintained, or which have been inspected under existing law, shall be examined and labeled under such rules and regulations as the Secretary of Agriculture shall prescribe, and then shall be allowed to be sold in interstate or foreign commerce.

■ [9] That no person, firm, or corporation, or officer, agent, or employee thereof, shall forge, counterfeit, simulate, or falsely represent, or shall without proper authority use, fail to use, or detach, or shall knowingly or wrongfully alter, deface, or

destroy, or fail to deface or destroy, any of the marks, stamps, tags, labels, or other identification devices provided for in this act, or in and as directed by the rules and regulations prescribed hereunder by the Secretary of Agriculture, on any carcasses, parts of carcasses, or the food product, or containers thereof, subject to the provisions of this act, or any certificates in relation thereto, authorized or required by this act or by the said rules and regulations of the Secretary of Agriculture.

[10] That the Secretary of Agriculture shall cause to be made a careful inspection of all cattle, sheep, swine, and goats intended and offered for export to foreign countries at such times and places, and in such manner as he may deem proper, to ascertain whether such cattle, sheep, swine, and goats are free from disease.

[11] And for this purpose he may appoint inspectors who shall be authorized to give an official certificate clearly stating the condition in which such cattle, sheep, swine, and goats are found.

[12] And no clearance shall be given to any vessel having on board cattle, sheep, swine, or goats for export to a foreign country until the owner or shipper of such cattle, sheep, swine, or goats has a certificate from the inspector herein authorized to be appointed, stating that the said cattle, sheep, swine, or goats are sound and healthy, or unless the Secretary of Agriculture shall have waived the requirement of such certificate for export to the particular country to which such cattle, sheep, swine, or goats are to be exported.

[13] That the Secretary of Agriculture shall also cause to be made a careful inspection of the carcasses and parts thereof of all cattle, sheep, swine, and goats, the meat of which, fresh, salted, canned, corned, packed, cured, or otherwise prepared, is intended and offered for export to any foreign country, at such times and places and in such manner as he may deem proper.

[14] And for this purpose he may appoint inspectors who shall be authorized to give an official certificate stating the condition in which said cattle, sheep, swine, or goats, and the meat thereof, are found.

[15] And no clearance shall be given to any vessel having on board any fresh, salted, canned, corned, or packed beef, mutton, pork, or goat meat, being the meat of animals killed after the passage of this act, or except as hereinbefore provided for export to and sale in a foreign country from any port in the United States, until the owner or shipper thereof shall obtain from an inspector appointed under the provisions of this act a certificate that the said cattle, sheep, swine, and goats were sound and healthy at the time of inspection, and that their meat is sound and wholesome unless the Secretary of Agriculture shall have waived the requirements of such certificate for the country to which said cattle, sheep, swine, and goats or meats are to be exported.

[16] That the inspectors provided for herein shall be authorized to give official certificates of the sound and wholesome conditions of the cattle, sheep, swine, and goats, their carcasses and products as herein described, and one copy of every certificate granted under the provisions of this act shall be filed in the Department of Agriculture, another copy shall be delivered to the owner or shipper, and when the cattle, sheep, swine, and goats or their carcasses and products are sent abroad, a third copy shall be delivered to the chief officer of the vessel on which the shipment shall be made.

[17] That no person, firm, or corporation engaged in the interstate commerce of meat or meat food products shall transport or offer for transportation, sell or offer to sell any such meat or meat food products in any State or Territory or in the District of Columbia or any place under the jurisdiction of the United States, other

than in the State or Territory or in the District of Columbia or any place under the jurisdiction of the United States in which the slaughtering, packing, canning, rendering, or other similar establishment owned, leased, operated by said firm, person, or corporation is located unless and until said person, firm, or corporation shall have complied with all of the provisions of this act.

[18] That any person, firm, corporation, or any officer or agent of any such person, firm, or corporation, who shall violate any of the provisions of this act shall be deemed guilty of a misdemeanor, and shall be punished on conviction thereof by a fine of not exceeding ten thousand dollars or imprisonment for a period of not more than two years, or by both such fine and imprisonment, in the discretion of the court.

[19] That the Secretary of Agriculture shall appoint from time to time inspectors to make examination and inspection of all cattle, sheep, swine, and goats, the inspection of which is hereby provided for, and of all carcasses and parts thereof, and of all meats and meat food products thereof, and of the sanitary conditions of all establishments in which such meat and meat food products hereinbefore described are prepared; and said inspectors shall refuse to stamp, mark, tag or label any carcass or any part thereof, or meat food product therefrom, prepared in any establishment hereinbefore mentioned, until the same shall have actually been inspected and found to be sound, healthful, wholesome, and fit for human food, and to contain no dyes, chemicals, preservatives, or ingredients which render such meat food product unsound, unhealthful, unwholesome, or unfit for human food; and to have been prepared under proper sanitary conditions, hereinbefore provided for; and shall perform such other duties as are provided by this act and by the rules and regulations to be prescribed by said Secretary of Agriculture; and said Secretary of Agriculture shall, from time to time, make such rules and regulations as are necessary for the efficient execution of the provisions of this act, and all inspections and examinations made under this act shall be such and made in such manner as described in the rules and regulations prescribed by said Secretary of Agriculture not inconsistent with the provisions of this act.

[20] That any person, firm, or corporation, or any agent or employee of any person, firm, or corporation, who shall give, pay, or offer, directly or indirectly, to any inspector, deputy inspector, chief inspector, or any other officer or employee of the United States authorized to perform any of the duties prescribed by this act or by the rules and regulations of the Secretary of Agriculture any money or other thing of value, with intent to influence said inspector, deputy inspector, chief inspector, or other officer or employee of the United States in the discharge of any duty herein provided for, shall be deemed guilty of a felony and, upon conviction thereof, shall be punished by a fine not less than five thousand dollars nor more than ten thousand dollars and by imprisonment not less than one year nor more than three years; and any inspector, deputy inspector, chief inspector, or other officer or employee of the United States authorized to perform any of the duties prescribed by this act who shall accept any money, gift, or other thing of value from any person, firm, or corporation, or officers, agents, or employees thereof, given with intent to influence his official action, or who shall receive or accept from any person, firm, or corporation engaged in interstate or foreign commerce any gift, money, or other thing of value given with any purpose or intent whatsoever, shall be deemed guilty of a felony and shall, upon conviction thereof, be summarily discharged from office and shall be punished by a fine not less than one thousand dollars nor more than ten thousand dollars and by imprisonment not less than one year nor more than three years.

[21]² That within the meaning of this act—

(a) A “farmer” means any person or partnership chiefly engaged in producing agricultural products on whose farm the number of cattle, calves, sheep, lambs, swine, or goats is in keeping with the size of the farm or with the volume or character of the agricultural products produced thereon, but does not mean any person or partnership engaged in producing agricultural products who—

(1) actively engaged in buying or trading in cattle, calves, sheep, lambs, swine, or goats; or

(2) actively engages, directly or indirectly, in conducting a business which includes the slaughter of cattle, calves, sheep, lambs, swine, or goats for food purposes; or

(3) actively engages, directly or indirectly, in buying or selling meat or meat food products other than those prepared by any farmer on the farm; or

(4) actively engages, directly or indirectly, in salting, curing, or canning meat, or in preparing sausage, lard, or other meat food products; or

(5) slaughters, or permits any person to slaughter, on his or their farm cattle, calves, sheep, lambs, swine, or goats which are not actually owned by him or them.

(b) A “retail butcher” means any person, partnership, association, or corporation chiefly engaged in selling meat or meat food products to consumers only, except that the Secretary of Agriculture, at his discretion, may permit any retail butcher to transport in interstate or foreign commerce to consumers and meat retailers in any one week not more than five carcasses of cattle, twenty-five carcasses of calves, twenty carcasses of sheep, twenty-five carcasses of lambs, ten carcasses of swine, twenty carcasses of goats, or twenty-five carcasses of goat kids, or the equivalent of fresh meat therefrom, and to transport in interstate or foreign commerce to consumers only meat and meat food products which have been salted, cured, canned, or prepared as sausage, lard, or other meat food products, and which have not been inspected, examined, and marked as “Inspected and Passed” in accordance with the terms of the Meat Inspection Act of March 4, 1907, and Acts supplemental thereto, and with the rules and regulations prescribed by the Secretary of Agriculture.

(c) A “retail dealer” means any person, partnership, association, or corporation chiefly engaged in selling meat or meat food products to consumers only except that the Secretary of Agriculture, at his discretion, may permit any retail dealer to transport in interstate trade or foreign commerce to consumers and meat retailers in any one week not more than five carcasses of cattle, twenty-five carcasses of calves, twenty carcasses of sheep, twenty-five carcasses of lambs, ten carcasses of swine, twenty carcasses of goats, or twenty-five carcasses of goat kids, or the equivalent of fresh meat therefrom, and to transport in interstate or foreign commerce to consumers only meat and meat food products which have been salted, cured, canned, or prepared as sausage, lard, or other meat food products which have not been inspected, examined, and marked as “Inspected and Passed” in accordance with the terms of the Meat Inspection Act of March 4, 1907, and Acts supplemental thereto, and with the rules and regulations prescribed by the Secretary of Agriculture.

That the provisions of the Meat Inspection Act of March 4, 1907, requiring inspection to be made by the Secretary of Agriculture shall not apply to animals slaughtered

² This paragraph is the amendment approved June 29, 1938 (52 Stat. 1235), to the Meat Inspection Act, and is therefore substituted for the concluding paragraph of the act as originally enacted. A retail butcher or a retail dealer must apply and qualify for a certificate of exemption from inspection before doing an interstate meat business.

by any farmer on the farm and sold and transported in interstate or foreign commerce, nor to retail butchers and retail dealers in meat and meat food products, supplying their customers: *Provided*, That all meat and meat food products derived from animals slaughtered by any farmer on the farm which are salted, cured, canned, or prepared into sausage, lard, or other meat food products at any place other than by the farmer on the farm upon which the animals were slaughtered shall not be transported in interstate or foreign commerce under the farmers' exemption herein provided, and all fresh meat and all farm-cured or prepared meat and meat products derived from animals slaughtered by any farmer on the farm which are to be used in interstate or foreign commerce shall be clearly marked with the name and address of the farmer on whose farm the animals were slaughtered: *Provided further*, That if any person shall sell or offer for sale or transportation for interstate or foreign commerce any meat or meat food products which are diseased, unsound, unhealthful, unwholesome, or otherwise unfit for human food, knowing that such meat food products are intended for human consumption, he shall be guilty of a misdemeanor and on conviction thereof shall be punished by a fine not exceeding \$1,000 or by imprisonment for a period of not exceeding one year, or by both such fine and imprisonment: *And provided further*, That the Secretary of Agriculture is authorized to maintain the inspection in this Act provided for at any slaughtering, meat canning, salting, packing, rendering, or similar establishment notwithstanding this exception, and that the persons operating the same may be retail butchers and retail dealers or farmers; and where the Secretary of Agriculture shall establish such inspection then the provisions of this Act shall apply notwithstanding this exception.

THE IMPORTED MEAT ACT

Extract from an act of Congress entitled "An act to provide revenue, to regulate commerce with foreign countries, to encourage the industries of the United States, to protect American labor, and for other purposes," approved June 17, 1930 (Public No. 361, 71st Cong.).

TITLE III—SPECIAL PROVISIONS

PART I—MISCELLANEOUS

* * * * *

SEC. 306. * * * Meats—importation prohibited in certain cases.

* * * * *

(b) Meats unfit for human food—No meat of any kind shall be imported into the United States unless such meat is healthful, wholesome, and fit for human food and contains no dye, chemical, preservative, or ingredient which renders such meat unhealthful, unwholesome, or unfit for human food, and unless such meat also complies with the rules and regulations made by the Secretary of Agriculture. All imported meats shall, after entry into the United States in compliance with such rules and regulations, be deemed and treated as domestic meats within the meaning of and subject to the provisions of the act of June 30, 1906 (Thirty-fourth Statutes at Large, page 674), commonly called the "meat inspection amendment," and the act of June 30, 1906 (Thirty-fourth Statutes at Large, page 768), commonly called the "food and drugs act," and acts amendatory of, supplementary to, or in substitution for such acts.

(c) Regulations.—The Secretary of Agriculture is authorized to make rules and regulations to carry out the purposes of this section, and in such rules and regula-

tions the Secretary of Agriculture may prescribe the terms and conditions for the destruction of all * * * meats, offered for entry and refused admission into the United States, unless such * * * meats be exported by the consignee within the time fixed therefor in such rules and regulations.

* * * * *

SEC. 653. Effective date of act.—Except as otherwise provided, this act shall take effect on the day following the date of its enactment.

HORSE MEAT ACT

Extract from an act of Congress entitled “An act making appropriations for the Department of Agriculture for the fiscal year ending June 30, 1920,” approved July 24, 1919 (41 Stat. 241).

For additional expenses in carrying out the provisions of the meat-inspection act of June 30, 1906 (Thirty-fourth Statutes at Large, p. 674), as amended by the act of March 4, 1907 (Thirty-fourth Statutes at Large, p. 1256), there is hereby appropriated for the fiscal year ending June 30, 1920, \$903,960, of which sum \$100,000 may be used for the inspection of equine meat in the manner provided in said act, as amended. And, hereafter, no person, firm, or corporation, or officer, agent, or employee thereof, shall transport or offer for transportation, and no carrier of interstate or foreign commerce, shall transport or receive for transportation from one State or Territory or the District of Columbia to any other State or Territory, or the District of Columbia or to any place under the jurisdiction of the United States or to any foreign country any of such meat or food products thereof unless plainly and conspicuously labeled, marked, branded, or tagged “Horsemeat” or “Horse-meat Product” as the case may be, under such rules and regulations as may be prescribed by the Secretary of Agriculture. All the penalties, terms, and provisions in said act, as amended, except the exemption therein applying to animals slaughtered by any farmer on a farm, to retail butchers and retail dealers in meat food products supplying their customers, are hereby made applicable to horses, their carcasses, parts of carcasses, and meat food products thereof, and the establishments and other places where such animals are slaughtered or the meat or meat food products thereof are prepared or packed for the interstate or foreign commerce, and to all persons, firms, corporations and officers, agents and employees thereof who slaughter such animals or prepare or handle such meat or meat food products for interstate or foreign commerce.

The Regulations for the enforcement of this act are given in “Regulations Governing the Meat Inspection Act of the United States Department of Agriculture (Edition of June 1952) and subsequent Amendments.

3. USDA GRADE STANDARDS AND INSPECTION SERVICE FOR PROCESSED FOODS*

The Branch of the Fruit and Vegetable Division, Agricultural Marketing Service of the U. S. Department of Agriculture, is engaged in two primary fields of activity. One is the development of grade standards—the other one is conducting and main-

* Excerpts from an address by F. L. Southerland, Chief of the Processed Products Standardization and Inspection Branch, Fruit and Vegetable Division, Agricultural Marketing Service United States Department of Agriculture, at a meeting of the Northwest Frozen Foods Association at Seattle, Washington, December 14, 1953.

taining an inspection service for processed fruits and vegetables, processed products thereof, and a large number of related or miscellaneous processed foods.

The Department has developed 116 grade standards for processed fruits and vegetables, processed products thereof, and related or miscellaneous processed foods. Thirty-four of these cover frozen fruits and vegetables.

Experience over the years has taught that certain basic principles are fundamental and must be employed in the development of practical and useful standards.

First among these principles is that the standards must be based on the actual styles, types, and quality gradations of the product being produced and marketed, and not on theoretical possibilities.

A second principle is that a standard must be national in scope. If the requirements in a standard are confined to special qualities produced in a particular area, excluding satisfactorily acceptable qualities of the same product produced in other areas, its usefulness, as a common language for trading, will be limited. The greater the concurrence in the requirements of a standard, the greater its value becomes as an aid in the marketing of the product.

As a third principle, a standard must take into consideration the important factors that affect the relative desirability of the product. They must cover inherent characteristics of the product and reflect the workmanship in the preparation of the raw materials and in the process of manufacture. Each grade provided by the standard must be carefully described and, whenever practical, a point score system should be included so that when it is applied, it will as nearly as possible indicate where the product ranks within a grade. This principle also involves basing the quality and other requirements for the different grades on good commercial practice.

The fourth principle involves a matter of options—that is, personal choice. A standard must provide for options, or as much personal choice, as possible with respect to style, type, or variety, product unit size or number of units per container, seasoning or sweetening ingredients, and size of container. It is highly desirable that provision for such options be made, so that a processor may produce and a buyer may select a product that will satisfy his needs and demands and at the same time will comply with the quality requirements of the standards.

The U. S. standards for processed foods provide for these personal choices to the fullest practical extent. In this connection, however, no provision for personal choice is provided which would permit deception or misrepresentation. Buyers should specify their preferences in their purchase contracts so there will be no misunderstanding when delivery is made.

The fifth principle requires the proper selection of the factors upon which the quality is to be based, so that the factors can be appropriately and consistently evaluated.

“Quality” in canned or frozen fruits and vegetables applies to the more superior qualities, the lowest qualities, and the qualities in between these extremes. Quality of a processed fruit or vegetable covers the inherent properties of the raw fruit or vegetable which determine the relative degree of excellence of the product, and also covers the effects of the treatment to which the product is subjected in preparing and processing it. The conditions under which the product is prepared, the packing media, if any, and added ingredients, if any, may also influence the degree of excellence of the finished product. A standard, then, must take into consideration as many of these factors or characteristics as possible which will permit evaluation by practical methods and which will reflect to the fullest extent possible the degree of excellence of the product.

Among the more important factors that influence the degree of excellence of a

processed fruit or vegetable are color, degree of freedom from defects or blemishes, extraneous and foreign materials, workmanship, product unit size and uniformity of size of units, stage of maturity or degree of ripeness, texture, tenderness, succulency, flavor, and odor.

A *sixth principle* involves adopting and incorporating in the standards objective tests and procedures for use in determining compliance with the requirements of the standards.

The processed foods inspection service is organized with 34 field laboratories, located in the major producing areas and in many of the large receiving markets. A control office, located in Washington, D. C., and three district offices, located in San Francisco, Chicago and New York City, are maintained to aid in directing, supervising, and coordinating the inspection activities. Basic instructions are formulated in the Washington, D. C. office, and flow to the field inspectors through the district and field offices.

A carefully supervised system of inspection by persons qualified and trained for inspection work is maintained. The inspectors are well trained in the interpretation of the U. S. grade standards and Federal Specifications.

Three different types of inspection service are made available to the industry. The more general type of service includes drawing representative samples from specific lots on which inspection is requested, in the processor's plant or in a warehouse or storage. The samples are examined to determine compliance with the various requirements outlined in the standards. Microscopic examinations and chemical and other analyses are made on the samples when necessary. The results of the inspection are reported on an official certificate which is issued to the applicant.

The second type of inspection is known as "continuous inspection." This type of inspection service provides for stationing an inspector, or as many inspectors as are necessary, at the processing plant during all shifts of the entire packing operation. The inspector checks the plant and equipment for sanitation; he observes the preparation of the raw material and he selects samples of the product at random during and after the processing and packing operations. He issues daily reports to the plant management, summarizing his observations and including a probable grade for each lot packed. When final inspection of the finished products is completed, he issues certificates as requested, showing the final grade of each lot packed.

The third type of inspection service is what may be termed "plant inspection-pack certification service." This type of service has become very popular. Under this service an inspector is assigned to the plant during the processing and packing season to inspect and certify each lot of the product as it is packed. The inspector also observes the preparation of the raw material and the cleanliness of the plant. The inspector need not, however, be present at all times during raw material preparation and processing operations, as is required under continuous inspection. Arrangements of this type of service can be made, however, to cover all shifts of operations if the applicant is willing to pay for it. Plant requisites for this type of service are not so exacting as for continuous inspection. However, plants must maintain acceptable standards of sanitation and use suitable raw materials to receive this type of service.

Another type of service is referred to as "inspection of unofficially submitted samples." This service consists of examining samples submitted by an interested party and issuing a certificate showing the pertinent facts concerning those samples only. Inspection certificates covering such samples do not identify the samples as representing any particular lot.

In order to make the inspection service available, it is necessary to assess and

collect fees that are sufficient to cover the cost of the service rendered. Fee rates for the different types of inspection service may be obtained from any field office or by writing to the Agricultural Marketing Service, U. S. Department of Agriculture, Washington, D. C.

An inspection certificate is a written report which shows the pertinent facts concerning the quality, condition, and grade or any part thereof, of a product. It includes useful descriptive information about the product and containers in which it is packed.

Since an inspection certificate contains a summary of the pertinent results of an inspection of a product, it may be useful to the applicant or to a financially interested party in one or more of the following ways:

1. It may serve as valuable information to processors, sellers, brokers, distributors and buyers of the class, quality, and condition of the product as determined by an authorized representative of the U. S. Department of Agriculture. For example, the certificate may be attached to the invoice or shipping documents to serve as evidence that the product complies with the quality requirements of the sales contract; or it may be used as evidence of the quality of the product by financially interested parties in negotiating sales.

2. It may serve as an aid in arriving at a loan value of the product.

3. It may serve as a guide in future packing operations; that is, it may indicate the need for the establishment or improvement of quality control at the plant where the product covered by the certificate was packed.

4. It may serve as an aid in making equitable settlements of disputes arising over claims by the owner for damage incurred in transit or in public storages.

5. It may serve as useful information to an interested party in appropriately labeling the product.

6. It may serve as valuable statistical data for financially interested parties, as well as a source of pertinent data for development of standards and specifications.

7. It may be introduced as evidence by interested parties in law suits or as an aid in the settlement of disputes without resorting to court action.

II. NUTRITION

1. NATIONAL RESEARCH COUNCIL NUTRITIONAL STANDARDS

FOOD AND NUTRITION BOARD, NATIONAL RESEARCH COUNCIL RECOMMENDED DAILY DIETARY ALLOWANCES¹,
REVISED 1953^a

DESIGNED FOR THE MAINTENANCE OF GOOD NUTRITION OF HEALTHY PERSONS IN THE U.S.A.

(Allowances are considered to apply to persons normally vigorous and living in temperate climate)

	Age, years	Weight kg. (lb.)	Height, cm. (in.)	Calories	Protein, gm.	Calcium, gm.	Iron, mg.	Vitamin A, I.U.	Thi- amine, mg.	Ribo- flavin, mg.	Niacin, mg.	Ascorbic acid, mg.	Vitamin D, I.U.
Men	25	65 (143)	170 (67)	3200 ²	65	0.8	12	5000	1.6	1.6	16	75	
	45	65 (143)	170 (67)	2900	65	0.8	12	5000	1.5	1.6	15	75	
	65	65 (143)	170 (67)	2600	65	0.8	12	5000	1.3	1.6	13	75	
Women	25	55 (121)	157 (62)	2300 ²	55	0.8	12	5000	1.2	1.4	12	70	
	45	55 (121)	157 (62)	2100	55	0.8	12	5000	1.1	1.4	11	70	
	65	55 (121)	157 (62)	1800	55	0.8	12	5000	1.0	1.4	10	70	
	Pregnant (3rd trimester)			Add 400	80	1.5	15	6000	1.5	2.0	15	100	400
	Lactating (850 ml. daily)			Add 1000	100	2.0	15	8000	1.5	2.5	15	150	400
Infants ³	0-1/12 ⁴												
	1/12-3/12	6 (13)	60 (24)	kg. × 120	kg. × 3.5 ³	0.6	6	1500	0.3	0.4	3	30	400
	4/12-9/12	9 (20)	70 (28)	kg. × 110	kg. × 3.5 ³	0.8	6	1500	0.4	0.7	4	30	400
	10/12-1	10 (22)	75 (30)	kg. × 100	kg. × 3.5 ³	1.0	6	1500	0.5	0.9	5	30	400
Children	1-3	12 (27)	87 (34)	1200	40	1.0	7	2000	0.6	1.0	6	35	400
	4-6	18 (40)	109 (43)	1600	50	1.0	8	2500	0.8	1.2	8	50	400
	7-9	27 (59)	129 (51)	2000	60	1.0	10	3500	1.0	1.5	10	60	400

	Age, years	Weight kg. (lb.)	Height, cm. (in.)	Calories	Protein, gm.	Calcium, gm.	Iron, mg.	Vitamin A, I.U.	Thi- amine, mg.	Ribo- flavin, mg.	Niacin, mg.	Ascorbic acid, mg.	Vitamin D, I.U.
Boys	10-12	35 (78)	144 (57)	2500	70	1.2	12	4500	1.3	1.8	13	75	400
	13-15	49 (108)	163 (64)	3200	85	1.4	15	5000	1.6	2.1	16	90	400
	16-20	63 (139)	175 (69)	3800	100	1.4	15	5000	1.9	2.5	19	100	400
Girls	10-12	36 (79)	144 (57)	2300	70	1.2	12	4500	1.2	1.8	12	75	400
	13-15	49 (108)	160 (63)	2500	80	1.3	15	5000	1.3	2.0	13	80	400
	16-20	54 (120)	162 (64)	2400	75	1.3	15	5000	1.2	1.9	12	80	400

¹ In planning practical dietsaries, the recommended allowances can be attained with a variety of common foods which will also provide other nutrient requirements less well known; the allowance levels are considered to cover individual variations among normal persons as they live in the United States subjected to ordinary environmental stresses. Other nutrients discussed in the text include: Carbohydrate and fat, Water, Sodium, potassium, and chlorine, Phosphorus, Copper, Iodine, Fluorine, Trace elements, Vitamin B₆ group, Vitamin B₁₂, Folicin, Pantothenic acid, Biotin, and Vitamin K.

² These calorie recommendations apply to the degree of activity for the reference man and woman described in the text. For the urban "white-collar" worker they are probably excessive. In any case, the calorie allowance must be adjusted to the actual needs of the individual as required to achieve and maintain his desirable weight.

³ The recommendations for infants pertain to nutrients derived primarily from cow's milk. If the milk from which the protein is derived is human milk or has been treated to render it more digestible, the allowance may be in the range of 2-3 gms. per kg. There should be no question that human milk is a desirable source of nutrients for infants even though it may not provide the levels recommended for certain nutrients.

⁴ During the first month of life, desirable allowances for many nutrients are dependent upon maturation of excretory and endocrine functions. Therefore no specific recommendations are given.

^a Nat. Acad. of Science-Nat. Res. Council Publ. #302, 1953

CONSIDERATION OF NUTRIENTS NOT TABULATED

Carbohydrate and Fat

Carbohydrates and fats are essential nutrients for energy, and in the pattern of the national diet of the United States they provide about 89 per cent of the calorie intake. Energy intake from carbohydrate and fat should be sufficient to avoid imposition on the utilization of protein. However, the optimum range for apportionment of carbohydrates and fats in meeting the calorie allowances is not known.

In the U.S.A. dietary, calories available from fat appear to have gradually increased from 32 to 40 per cent of the total calories in the period from 1909 to 1952.⁵ The extent to which this represents a real increase in consumption is questionable because of the lack of information on wastage. Whether the increase is nutritionally desirable is also questionable. Little information is available on the human requirement for fat. While a requirement for certain unsaturated fatty acids, notably linoleic and arachidonic acids, in natural fat, has been demonstrated with experimental animals, the human need for these fatty acids is unknown. In any event, adequate amounts are readily available in ordinary diets in which fat provides as much as 20 per cent of the total calories. The association of dietary fat with obesity and degenerative disease remains to be elucidated in relation to total calorie intake.

The relative nutritional merits of sugars and starches as compared with the more complex polysaccharides are difficult to assess. Differences in utilization of nutrients in synthetic diets with different carbohydrates have been noted in experimental animals, but the applicability to human nutrition is unknown. Likewise, little is known as to the importance of the indigestible fractions of plant food products in relation to intestinal function. Recommended allowances for carbohydrates and fats cannot be formulated as yet.

Water

A suitable allowance of water for adults is 2.5 liters daily in most instances. An ordinary standard is one milliliter for each calorie of food. Much of this quantity is contained in prepared foods. Water should be allowed *ad libitum*. Sensations of thirst usually serve as adequate guides to intake, except for infants and sick persons. Under conditions of extreme heat or excessive sweating, the sensation of thirst may not keep pace with the actual water requirements, and forced intakes up to one liter per hour may be indicated for a short time.

Sodium, Potassium, and Chlorine

These three elements are indispensable dietary constituents and function prominently in the maintenance of water balance. Potassium is especially abundant in both plant and animal tissues and does not need consideration as a dietary adjunct.

The average intake of sodium chloride (salt) for the normal adult is 7 to 15 grams daily. This includes sodium and chlorides contained in foods as well as those added to food as salt. It more than meets the normal requirements. The requirement for sodium chloride is increased by environmental and climatic conditions associated with increased sweating. Under unusual conditions, such as doing heavy work in a hot climate, 10 to 15 grams daily, or even more, may be required with meals and in drinking water. However, after acclimatization to heat the sodium content of sweat is greatly reduced and the allowance for salt can be near to normal.

Phosphorus

In the original table no allowances were formulated for phosphorus because of the view that dietary deficiencies of phosphorus are uncommon and that diets which are adequate in other respects, particularly in calcium, are ordinarily adequate in phosphorus. In preparation for the 1945 revision, a large amount of published and unpublished data from balance studies was brought together and evaluated. The evidence indicates that the phosphorus allowances should be at least equal to those for calcium in the diets of children and of women during the latter part of pregnancy and during lactation. For other adults the phosphorus allowances should be approximately one and one-half times those for calcium. When the calories are obtained largely from cereals, computation of the total phosphorus intake may be misleading because phytin phosphorus may be poorly utilized unless the supply of vitamin D is adequate. In general, it is safe to assume that if the calcium and protein needs are met through common foods, the phosphorus requirement also will be covered, because the common foods richest in calcium and protein are also the best sources of phosphorus.

Copper

The requirement for copper for adults is about 1 to 2 milligrams daily. Infants and children require approximately 0.05 milligrams for each kilogram of body weight. The requirement for copper is approximately one-tenth that for iron. A good diet normally will supply sufficient copper.

Iodine

The requirement for iodine is small, probably about 0.002 to 0.004 milligrams daily for each kilogram of body weight, or a total of 0.15 to 0.30 milligrams daily for the adult. This need is met by the regular use of iodized salt; its use is especially important in *adolescence* and *pregnancy*.

Fluorine

Small amounts of fluoride are generally present in plant and animal tissues, especially in bones and teeth. No conclusive evidence that fluorides have an essential function in nutrition or metabolism has been adduced. However, extensive evidence indicates that during tooth development a controlled intake of fluoride, such as is provided by drinking water containing about 1 part per million, results in substantial protection against dental caries. This practice is recognized as an important public health measure.

Trace Elements

Certain trace elements (also referred to as micro-, rare, minor, and oligo-elements or micronutrients) commonly found qualitatively in biological organisms have functional significance most frequently associated with enzyme systems. Other than that the amounts are exceedingly small, relatively little is known about the quantitative levels necessary for essential physiological function of these elements in human nutrition, and less is known about desirable dietary levels. Sufficient amounts are undoubtedly present in ordinary diets. The possibility of antagonisms between metals and of intoxication must be considered along with any attempt to correct suspected deficiencies of the trace elements.⁹ Among those not noted elsewhere which presumptive evidence would indicate to be essential, mention may be made of cobalt, magnesium, manganese, molybdenum, and zinc.

Vitamin B₆ Group

Vitamin B₆ is a complex of three closely related chemical compounds: pyridoxine, pyridoxal, and pyridoxamine. Pyridoxal phosphate has been shown to be the active coenzyme form of this complex.¹⁷ Vitamin B₆ occurs in animal products largely as pyridoxal and pyridoxamine, in plant products as pyridoxine.²³ In animals, the three forms are equally active when given separately from the diet, but pyridoxine is the most active when given with food.²⁹ In the rat, vitamin B₆ is synthesized by intestinal organisms¹⁴ and may be available to the animal for an appreciable part of metabolic needs. Whether this is true of the human being has not yet been established.

Several common nutrients increase the need for vitamin B₆ in animals. Among these are methionine,¹³ protein,¹² linseed oil,¹⁹ and sucrose.²⁵ On the other hand, certain substances such as choline, aureomycin, essential fatty acids, biotin, and pantothenic acid²⁷ seem to decrease the requirement. Certain biochemical functions of vitamin B₆ have been reported.^{11, 15, 16}

The need for and function of vitamin B₆ in human nutrition has been demonstrated only recently,^{22, 26, 30, 32} though there are several earlier indications of its essentiality.^{16, 18, 28, 31} Rough estimates of human vitamin B₆ requirements may be made from certain animal experiments²⁴ and tests with humans.²² Balance studies^{20, 21} are questionable for this purpose, since no evidence is available on the effect of intestinal synthesis. The evidence available indicates that the daily intake of vitamin B₆ should be from 1 to 2 milligrams, an amount which is readily provided by ordinary mixed diets.

Vitamin B₁₂

Vitamin B₁₂ has been found to be an essential nutrient in many animal species and its metabolic functions have been the subject of wide investigation.³⁸ In man, observations on the hemopoietic activity of vitamin B₁₂ support the suggestion⁴⁴ that approximately 1 microgram daily parenterally will allow replacement of the lack in pernicious anemia. Present information is not sufficient to permit extrapolation of this estimate to the dietary requirement of healthy adults.

The provision of supplementary vitamin B₁₂ to premature infants has not resulted in growth stimulation.^{37, 39} It appears probable that normal infants being fed on cow's milk formulas or on breast milk receive sufficient vitamin B₁₂ to meet their needs.⁴⁰

Some workers have reported data interpreted as indicating a growth stimulation in children.³⁵ Data from other studies^{34, 41} fail to provide evidence of effectiveness of vitamin B₁₂. These investigations are of varying quality, but each is subject to one or more of the following limitations: smallness of samples, failure to match age and sex grouping in control and supplemented groups, failure to eliminate psychologic factors, inadequate information concerning dietaries of the individuals studied, and the absence of information on the vitamin B₁₂ content of the foods consumed.³³ The data available are insufficient as a basis for a recommended dietary allowance of vitamin B₁₂.

Folacin

Since the 1948 revision of the Recommended Dietary Allowances little additional information bearing directly upon the dietary intake of the pteroylglutamates or the quantitative estimates of needs has been reported. A useful compilation of the folic acid activity in foods⁴² has appeared. Unfortunately, methods for the estimation of the individual members of the folacin group of substances have not been widely

applied, and the microbiological procedures sometimes present difficulties because of the presence of stimulants other than folacin.⁴³ Hence, dependable values on the dietary intake of folacin under a variety of conditions are not available.

In several instances therapeutic responses to folic acid following administration of 1 milligram daily are recorded.³⁶ Woodruff, Peterson, and Darby⁴⁵ have recorded effective therapeutic response of two cases of megaloblastic anemia in infancy to oral doses of 500 and 200 micrograms per day, respectively. These low therapeutically effective doses are in agreement with an estimate of the human requirement of this factor made by extrapolating the results of studies on monkeys, chickens, and turkeys on a caloric basis. It seems probable that dietary intakes of the order of less than a milligram per day can be expected to cover any nutritional needs for folic acid activity. The actual requirement or allowance cannot be set at this time.

Pantothenic Acid

Pantothenic acid is a part of coenzyme A which mediates acetylation and many other acylation reactions. It is intimately involved in the aerobic utilization of carbohydrates, in the synthesis and degradation of fatty acids, sterols, steroid hormones, etc., and in a number of other processes. Pantothenic acid deficiency has been induced in every animal in which it has been seriously attempted and always results in severe symptoms and eventual death. It is a practical certainty that pantothenic acid is required in human nutrition. It has been reported to improve the reactions of young men to stress⁴⁷ and to relieve the burning feet syndrome.⁴⁶ The amount of pantothenic acid consumed daily with 2500 calories of good diet is approximately 10 milligrams.⁴⁹

Biotin

The exact mode of functioning of biotin in enzymatic systems has not been elucidated. It is, however, evident that the vitamin is required directly or indirectly for several reactions in which carbon dioxide is fixed in mammalian and bacterial systems. In the latter systems, evidence for its participation in the synthesis of unsaturated fatty acids also is strong. Intestinal synthesis of this vitamin is extensive and tends to prevent the development of deficiency. However, dietary deficiencies are demonstrable in rapidly growing animals following the administration of sulfonamides. Biotin deficiency symptoms have been induced in human beings by feeding raw egg white and have been alleviated by a biotin concentrate. Hence its need by human beings may be said to have been directly demonstrated.⁴⁸

Vitamin K

The amount of vitamin K required for maintenance of a normal prothrombin level in the blood is easily provided when an average diet is ingested. However, special attention to this vitamin is desirable in the latter part of pregnancy and for the newborn infant. Pregnant women usually have normal amounts of prothrombin in the blood, but many newborn infants have abnormally small amounts. Although little relation seems to exist between the amount of prothrombin in the blood of the mother and that of the infant at birth, the amount of vitamin K received by the mother is reflected quickly in the amount of prothrombin in the blood of her infant *in utero*. Seldom does the mother have enough vitamin K without supplement to prevent an important decrease in the prothrombin level of the blood of her infant during the first days after birth.

The customary concept that regulation of the amount of prothrombin is the only function of vitamin K has been brought into question and its implication in brain hemorrhage and damage has been reported.⁵⁰ In view of the very large number of babies with intracranial damage at birth and the possible relationship of these lesions to vitamin K deficiency, it is suggested that a daily oral dose of 1 milligram of vitamin K be given to pregnant women during the last month of pregnancy. If the mother has been treated in this manner the newborn infant needs no supplement of vitamin K during the short period preceding ingestion of food.

When the vitamin K status of the mother has been unsatisfactory or is unknown at the time of labor, it is desirable that this vitamin be given to the mother before the birth of the baby, or to the baby immediately after birth, preferably the former. It has been demonstrated that the prothrombin level of the baby is higher in the first days after birth if vitamin K is given to the mother before delivery than if it is given to the baby at birth. A suitable amount for the mother preceding delivery is 1 milligram administered parenterally; this amount will stabilize the prothrombin level of the infant until food is taken. A suitable amount for the infant after birth is 1 milligram for a single dose. In fact it has been shown that a single dose of 10 to 20 micrograms is adequate to cover the first 5 days. The daily requirement of the infant is approximately 1 microgram.⁵¹

General Discussion

The recommended allowances for adults are given in terms of a reference man and reference woman both aged 25, living in a temperate climate and weighing 65 and 55 kilograms, respectively; these standard persons are assumed to be fairly active physically, being neither sedentary nor engaged in hard manual labor, as described in the section on calories. Adjustment should be made for persons who differ from the standard in body size, age, or physical activity. Allowances for infants and children are given for age groups and, after the age of ten, for boys and girls separately, since the growth curves and levels of activity differ significantly from about this age. Allowances are based on the needs for the middle year in each group and are for normal activity and for the weights indicated in the table. As with adults, adjustments should be made for children who differ in size and activity from the standard.

The breakdown into three periods of infancy is an innovation of this revision of the Recommended Dietary Allowances. Recognition is given to the differences in the recommended allowances for infants and the nutrient levels supposedly provided by maternal lactation. References 4 and 6 may be consulted for further detail in this regard.

The recommended allowance values of the table are for nutrients in foods as consumed and do not take into consideration prior losses in storage, cooking, and serving. Provision should be made for these losses in planning practical dietaries. The allowances do provide for possible incomplete availability or absorption of certain nutrients such as iron and carotene.

The allowances are intended to serve as a guide for planning adequate diets for substantially all normal healthy persons in the United States. It is recognized that the biological normal consists of a range of values. The allowances are designed to provide for requirements in the high normal range as well as for the average.

The allowances are expected to cover short-term needs and also to maintain good nutrition for the life span as a whole, although little is known of long-term requirements. There is evidence from studies on animals that benefits accrue during a

lifetime when the intake of certain nutrients is considerably higher than minimal need. It should be emphasized that the allowances apply only to persons in good health. This is particularly true for women during pregnancy. Requirements vary greatly in disease; in febrile illnesses and other hypermetabolic states, the need for certain nutrients may be markedly increased, while in diseases of the gastrointestinal tract, absorption of nutrients may be seriously impaired.

The recommended allowances for the various nutrients, with the exception of vitamin D, can be obtained through a good diet of common foods. The dietary pattern of seven basic food groups presented in the National Food Guide⁷ has been widely used in the United States as an aid for selection of adequate diets. It is obvious that this guide serves only as a rough approximation of nutrient intake. Consistently poor choice of foods from each of the seven groups can result in an inadequate diet.

Some foods are important because of their unique nutritional contribution and cannot easily be replaced.¹ Milk is an important source of protein, calcium, riboflavin, and other nutrients. Citrus fruits and tomatoes are outstanding sources of vitamin C, although significant quotas may be obtained from other fruits, potatoes, and most leafy, green, and yellow vegetables, in spite of losses during food preparation in the latter groups. For some population groups, such as pregnant and lactating women, consistent selection of foods of high nutritive quality is essential or it will be difficult to meet needs without an excess of calories. These and similar problems will arise with the use of any type of food guide.

Quantitative guides for the selection of an adequate diet at different food cost levels have been published by various national, state, and local groups. Those available from the U. S. Department of Agriculture are listed in the references.^{3, 8} A commendable booklet entitled "A Balanced Diet" is available from the Nutrition Foundation, Inc.² A comprehensive tabulation of food composition has been published by the U. S. Department of Agriculture.¹⁰

Again the point must be emphasized that foods selected to provide the specific nutrients for which quantitative allowances have been recommended are most likely to provide also the other essential nutrients for which quantitative requirements have not been adequately determined.

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2. FOOD CONSUMPTION TABLE

NUTRITION—APPARENT CIVILIAN PER CAPITA CONSUMPTION OF MAJOR FOOD COMMODITIES: 1935 TO 1952*

[In pounds. Data on calendar year basis except as follows: Dried fruit, pack year, fresh citrus fruits and rice, crop year beginning previous year; peanuts, crop year beginning September of year indicated. See also *Historical Statistics*, series C 128-155.]

Commodity	1935-39, average	1946	1947	1948	1949	1950	1951	1952 ¹
Meats (carcass weight), total	126.2	153.2	154.3	144.6	143.7	143.5	137.6	142.0
Beef	55.2	61.3	69.1	62.7	63.5	63.0	56.1	60.4
Veal	8.1	9.9	10.8	9.5	8.8	8.0	6.6	7.0
Lamb and mutton	6.8	6.6	5.3	5.0	4.1	3.9	3.4	3.9
Pork (excluding lard)	56.1	75.4	69.1	67.4	67.3	68.6	71.5	70.7
Fish (edible weight), total	11.1	11.0	10.6	11.0	11.4	11.5	11.5	11.4
Fresh and frozen	5.3	6.2	6.2	6.3	6.4	6.3	6.4	(²)
Canned ³	4.8	3.8	3.6	3.8	4.1	4.3	4.2	(²)
Cured	1.0	1.0	.8	.9	.9	.9	.9	(²)
Poultry products:								
Eggs	37.3	47.1	47.6	48.3	47.7	48.2	51.6	52.7
Eggs (number)	298	377	381	387	381	386	397	406
Chicken (dressed weight)	17.9	25.7	23.5	23.1	25.1	26.4	28.8	29.5
Turkey (dressed weight)	2.6	4.5	4.4	3.7	4.1	4.9	5.2	5.6
Dairy products:								
Total milk (whole milk equivalent) ⁴	801	813	787	751	761	776	757	(²)
Cheese	5.5	6.7	6.9	6.9	7.2	7.7	7.2	7.5
Condensed and evaporated milk	16.7	18.5	20.3	20.1	19.6	20.0	18.2	17.9
Fluid milk and cream ⁴	340	423	398	387	384	385	395	400
Fats and oils, total, fat content	44.7	39.7	41.8	42.4	42.2	45.4	41.8	43.7
Butter, farm and factory (actual weight)	16.7	10.5	11.1	9.9	10.4	10.7	9.6	8.7
Lard	11.0	11.8	12.5	12.7	11.7	12.1	12.2	12.2
Margarine (actual weight)	2.9	3.8	5.0	6.1	5.7	6.1	6.5	7.7
Shortening	11.7	10.1	9.3	9.7	9.7	11.0	9.0	10.0
Other edible fats and oils	6.3	6.2	6.9	7.2	7.8	8.8	7.6	8.3
Fruits:								
Fresh, total ⁴	138.5	138.3	143.5	130.6	125.0	110.1	117.7	113.0
Citrus ⁴	48.9	58.7	61.8	53.9	47.4	40.9	44.8	44.3
Apples (commercial)	30.4	23.2	25.3	25.8	24.8	23.1	25.6	22.7
Other (excluding melons)	59.2	56.4	56.4	50.9	52.8	46.1	47.3	46.0
Processed:								
Canned fruit	14.9	21.8	18.2	18.0	18.2	20.9	18.7	19.7
Canned juices	3.9	17.7	15.5	17.3	15.4	13.8	14.8	13.9
Frozen	.8	3.1	3.2	3.0	3.5	4.3	4.7	5.5
Dried	5.8	4.6	4.0	4.2	4.6	4.4	4.4	4.5
Vegetables:								
Fresh ⁴	235	272	252	261	249	252	254	241
Canned	29.9	46.5	40.2	37.6	38.6	41.8	41.4	41.2
Frozen	5.4	2.0	2.6	3.0	3.0	3.3	4.1	4.2
Potatoes ⁴	131	127	124	113	108	104	104	102
Sweetpotatoes ⁴	21.4	18.2	15.9	13.0	14.3	12.8	6.5	7.5
Dry edible beans ⁴	8.8	8.7	6.4	6.8	7.0	8.6	8.4	8.5
Sugar (refined)	97.0	74.4	91.1	95.7	95.1	95.5	96.3	92-96
Grains:								
Corn products:								
Corn meal	22.9	15.9	14.0	13.8	13.5	13.2	12.7	12.5
Corn sirup	7.6	11.8	12.8	8.2	8.5	9.1	9.0	9.0
Corn starch	1.3	1.8	1.9	1.7	1.8	1.9	1.9	1.9
Corn sugar	2.7	3.8	4.5	4.0	4.1	4.5	4.1	4.0
Breakfast cereals	1.6	1.9	1.4	1.5	1.5	1.5	1.5	1.5
Hominy	1.4	2.7	3.1	2.9	2.7	2.7	2.7	2.7

Commodity	1935-39, average	1946	1947	1948	1949	1950	1951	1952 ¹
Grains:								
Oatmeal	3.9	3.1	2.8	2.9	2.9	3.0	3.0	3.0
Barley food products ⁶	1.4	2.0	1.9	1.5	1.5	1.4	1.4	1.4
Wheat:								
Four ⁷	159	156	138	137	135	133	133	133
Breakfast cereals	3.7	3.3	3.3	3.3	3.3	3.3	3.3	3.3
Rye flour	2.2	1.8	1.3	1.4	1.5	1.5	1.5	1.5
Rice, milled	5.6	4.0	4.7	5.0	5.0	5.0	5.8	5.5
Beverages:								
Coffee ⁸	14.0	19.9	17.3	18.3	18.6	16.1	16.4	16.4
Tea	.67	.57	.58	.57	.59	.60	.65	.64
Cocoa beans	4.4	4.2	4.1	3.8	4.0	4.3	4.0	4.0
Peanuts (shelled)	4.3	5.0	4.6	4.3	4.2	4.4	4.4	4.4

* Reproduced from Statistical Abstracts of the United States, 1953.

¹ Preliminary.

² Data not available.

³ Excludes canned food products containing small quantities of fish such as clam chowder, etc.

⁴ Series in process of revision as result of 1950 Census of Agriculture for all years for total milk, fluid milk and cream, fresh vegetables; 1946 through 1950 for total fresh fruit, fresh citrus fruit; and 1946 through 1949 for potatoes, sweetpotatoes, dry beans.

⁵ Average for 1937-39.

⁷ Comprises white, whole wheat, and semolina flour.

⁶ In terms of malt equivalent.

⁸ Green bean basis.

Source: Department of Agriculture, Bureau of Agricultural Economics; published quarterly in *National Food Situation*.

3. NUTRITIONAL VALUE TABLE

NUTRITION—NUTRIENTS AVAILABLE FOR CIVILIAN CONSUMPTION PER CAPITA PER DAY: 1935 TO 1952*

[Computed on basis of estimates of apparent civilian consumption (retail basis) including consumption from urban gardens. No deductions have been made in nutrient estimates for loss or waste in home or for destruction or loss of nutrients during preparation of food. Deductions have been made for inedible refuse. Data for iron, thiamine, riboflavin and niacin include amounts of these nutrients added to prepared cereals, bread, and white flour under enrichment program. See also *Historical Statistics*, series C 122-127]

Nutrients	Units	1935-39, average	1946	1947	1948	1949	1950	1951	1952 (prel.)
Food energy	Cal	3,280	3,390	3,330	3,260	3,230	3,270	3,240	3,250
Protein	Grams	89	104	97	94	94	94	95	96
Fat	Grams	132	147	142	142	141	146	141	146
Carbo-hydrate	Grams	431	417	411	402	401	399	402	394
Calcium	Grams	.94	1.15	1.08	1.05	1.05	1.06	1.07	1.08
Iron	Mg	13.6	18.6	17.3	16.5	16.5	16.3	16.5	16.5
Vitamin A value	I. U.	8,100	9,500	8,800	8,600	8,600	8,500	8,000	8,100
Thiamine	Mg	1.43	2.18	1.96	1.93	1.90	1.90	1.95	1.93
Riboflavin	Mg	1.86	2.58	2.42	2.35	2.34	2.35	2.36	2.38
Niacin	Mg	15.2	21.3	19.8	19.0	19.0	19.0	19.0	19.0
Ascorbic acid	Mg	115	137	129	125	121	117	122	118

Source: Department of Agriculture, Bureau of Human Nutrition and Home Economics; published quarterly in *National Food Situation*.

* Reproduced from statistical abstracts of the United States (1953).

4. STATEMENT OF GENERAL POLICY IN REGARD TO THE ADDITION OF SPECIFIC NUTRIENTS TO FOOD*

During the 1930's certain nutritional deficiencies were prevalent in the population of the United States, and newly developed synthetic vitamins were being used in foods with little or no scientific guidance. In 1939, and again in 1946, the Council on Foods and Nutrition of the American Medical Association adopted its policies on the proper additions of vitamins and minerals to foods. In 1941 the Food and Nutrition Board (originally the Committee on Foods and Nutrition) of the National Research Council likewise adopted a policy on the addition of specific nutrients to foods. These statements of policy have now been reconsidered jointly by the Food and Nutrition Board and the Council on Foods and Nutrition in the light of experience and of new developments. There is good evidence to indicate that the policies have been beneficial to the public and have encouraged sound nutritional practices. The policies are therefore reaffirmed in principle, and with revision of wording are embodied in the following statements:

(1) With carefully defined limitations, the principle of the addition of specific nutrients to certain staple foods is endorsed for the purpose of maintaining good nutrition as well as for correcting deficiencies in the diets of the general population or of significant segments of the population. The requirements for endorsement of the addition of a particular nutrient to a particular food include (a) clear indications of probable advantage from increased intake of the nutrient, (b) assurance that the food item concerned would be an effective vehicle of distribution for the nutrient to be added, and (c) evidence that such addition would not be prejudicial to the achievement of a diet good in other respects. These requirements have been met in the specific cases indicated in paragraph (6).

(2) The desirability of meeting the nutritional needs of the people by the use of natural foods as far as practicable is emphasized, and to that end education in the proper choice and preparation of foods and the betterment of food production, processing, storage, and distribution so as to provide more fully the essential nutrients native thereto are to be encouraged.

(3) In order to avoid undue artificiality of food supply, foods chosen as vehicles for the distribution of additional nutrients should be, whenever practicable, those foods which have suffered loss in refining or other processing, and the nutrients added to such foods should preferably be the kinds and quantities native to the class of foods involved.

(4) The addition of other than natural levels of nutrients to foods which are suitable vehicles of distribution may be favored when properly qualified judgment indicates that the addition will be advantageous to the public health and when other methods for effecting the desired purpose appear to be less feasible.

(5) Whenever technologic and economic developments lead to extensive reduction in the consumption of a staple food, with a consequent nutritionally significant reduction in the intake of an essential nutrient or nutrients, consideration by qualified bodies should be given to the desirability of restoring such nutrient or nutrients to the dietary.

(6) The endorsement of the following is reaffirmed: the enrichment of flour, bread,

* Adopted jointly by the Food and Nutrition Board, National Research Council—National Academy of Sciences, and the Council on Foods and Nutrition, American Medical Association, November 1953.

degerminated corn meal, and corn grits; the nutritive improvement of whole grain corn meal and of white rice; the retention or restoration of thiamine, niacin, and iron in processed food cereals; and the addition of vitamin D to milk, of vitamin A to table fats, and of iodine to table salt.

III. SPECIAL FOOD AGENCIES

1. THE FOOD AND NUTRITION BOARD OF THE NATIONAL RESEARCH COUNCIL

LeRoy Voris

Executive Secretary

The ultimate interpretation and evaluation of the results of scientific research in relation to their application to public policy and welfare is in most countries related to agencies within the government. To some extent this is true in the United States, but when problems arise which require the best scientific consultation, government agencies frequently seek the advice of a nongovernmental agency which exists for the purpose, namely, the National Research Council. Within the organizational structure of the National Research Council, the Food and Nutrition Board serves in relation to the collective sciences of foods and nutrition.

The National Research Council is a cooperative organization of the scientific men of America. It was established in 1916 by the National Academy of Sciences at the request of President Woodrow Wilson who later in 1918 perpetuated its existence by executive order. The major scientific and technical societies cooperated in setting up the NRC and continue to play the major role in maintaining its organization. The membership of the Council is composed largely of representatives of these societies, other research organizations, and government agencies. Membership includes not only scientific and technical men but also business men interested in engineering and industry. All members receive appointments from the President of the National Academy of Sciences.

The Council receives no governmental appropriation for its support and is thus able to maintain an independent and unprejudiced position in all matters of a scientific nature. Members of the Council and its various committees serve without compensation except for reimbursement of expenses incurred in attending meetings involving business of the NRC.

The Council does not maintain scientific laboratories. It is designed rather to integrate the work of individual scientists and to assist in coordinating, in some measure, scientific attack in America upon large problems in the fields of scientific inquiry. The Council is perhaps most competent in connection with problems which depend for successful solution on the cooperation of workers and laboratories within a single science or dealing with a composite problem which cuts across several branches of science. In such activities the function of the Council is mainly to provide the facilities whereby the attention of scientific men of the country can be focused on any particular problem of national interest.

The Food and Nutrition Board has functioned within the National Research Coun-

cil through the Division of Biology and Agriculture since 1940 and has grown into one of the most active operating boards. The Board is committed to develop, recommend, and encourage policies, research, and education by government or other agencies which will provide for the maximum nutritional welfare of our people.

The birth and development of the Food and Nutrition Board is illustrative of how some government activities filter through to the NRC. The national emergency situation in 1940 led the President to set up a National Defense Council in which was established a Consumer Protection Division under the direction of Miss Harriet Elliott. This division was to include in its functions a health and welfare program. Miss Elliott appointed Mr. M. L. Wilson, Director of the Extension Service of the Department of Agriculture, to head a national nutrition program as one of the primary elements of the health and welfare activities.

It was recognized that any nutrition program which would be successful in promoting the nutritional welfare of the population must be based on the best scientific judgment. For this reason, the NRC was asked to set up a Committee on Food and Nutrition. This committee, under the chairmanship of Dr. Russell M. Wilder, held its first meeting in November 1940. By late 1941, the committee's activities had branched out into a root structure of subcommittees so numerous that the committee was redesignated as the Food and Nutrition Board of the National Research Council, and the subcommittees were given full standing as committees which reported to the Board for final action on their special projects. Dr. Wilder was succeeded by Dr. Frank G. Boudreau, who guided the Board through the war time period and continued as chairman in its peacetime program until 1950. He was succeeded by Dr. L. A. Maynard.

A Board is only an abstract expression for the group of individuals of which it is composed. The members of the Food and Nutrition Board are selected by the National Research Council on the basis of demonstrated leadership in the science of foods and nutrition. They are chosen especially for those qualifications which enable them to interpret the results of food and nutrition research in terms of its broad applications and implications in national and world affairs. In addition to the membership body, which consists of 24 members, the Board maintains liaison representation with appropriate government agencies and scientific societies. It has usually about 15 active committees, the membership of which constitutes a panel of approximately 100 consultants. A permanent secretariat is maintained under the administration of the NRC for the purpose of coordinating committee activities and advancing the operational activities and programs developing from the semi-annual meetings.

As with other NRC functions, the Board is financially dependent on gifts, grants, and contracts. Contracts are undertaken for specific projects and do not contribute to the maintenance of persistent operating expenses.

The Board is particularly indebted to the Milbank Memorial Fund, the Nutrition Foundation, and the Williams-Waterman Fund of the Research Corporation for continued support of its general program.

A detailed review of the role which the Board has played since its beginning would fill volumes. It may suffice here to illustrate the scope and tenor of the Board's activities by briefly sketching some of the major problems with which it has been involved.

Among the first actions of the Board was the attempt to develop goals of nutrient intake toward which dietitians and planners of the food supply might aspire with the objective of adequately insuring the nutritional health of the nation's population. Thus there came into being the Recommended Dietary Allowances of the Na-

tional Research Council, which have been widely publicized and used extensively for a variety of purposes. The Recommended Dietary Allowances have frequently been misused as requirements or standards and, when applied as such to individual or selected segments of the population, may have led to unwarranted conclusions. The Board early recognized the wide variations of individual requirements for the known essential nutrients. Therefore it adopted the expedient of setting the recommended allowances high enough to include that fraction of the population which might reveal incipient signs of deficiency if held to the level of requirement indicated for the average individual. The Recommended Dietary Allowances were originally developed by a committee under the guidance of Dr. Lydia J. Roberts and have been periodically revised as new evidence has accumulated. The 1953 revised edition of *Recommended Dietary Allowances* was published as NRC Publication No. 302.

As a natural consequence of the establishment of the Recommended Dietary Allowances, it was necessary to develop Tables of Food Composition in terms of the nutrients included in the allowances from which a dietary of ordinary foodstuffs might be designed to provide the allowances at the levels proposed. This was accomplished by a Committee on Food Composition under the chairmanship of Dr. C. A. Elvehjem. In collaboration with the Bureau of Human Nutrition and Home Economics of the USDA and the Quartermaster Food and Container Institute for the Armed Forces, this committee prepared *Tables of Food Composition in Terms of Eleven Nutrients*, published as USDA *Miscellaneous Publication* No. 572.

Although the Board deemed it desirable to attain the recommended dietary allowances from ordinary foods insofar as possible, it became evident early in the Board's deliberations that some vitamins and minerals natural to some foods, particularly cereals, were being lost for human consumption during processing. Among these nutrients, it appeared that thiamine, riboflavin, niacin, and iron might be replaced in white flour in order to insure a more adequate intake by a population in which refined cereal products constitute a major portion of the diet.

Thus the enrichment program for bread and flour was initiated. A history of the enrichment movement for flour and bread was published in 1944 as NRC *Bulletin* No. 110. In addition to the enrichment of white flour and bread, the Committee on Cereals, under the direction of Dr. R. R. Williams, has sponsored an enrichment program for corn products and a study of the potential nutritional improvement of white rice. The latter study was published in 1945 as NRC *Bulletin* No. 112.

In spite of its active promotion of the cereal enrichment program, the Board from the beginning was aware of the hazards of public exploitation through the indiscriminate addition of vitamins to foods and has adhered consistently to a general policy in the matter of addition of specific nutrients to foods. The statement modified only slightly from a 1941 version was issued jointly in 1953 by the Board and the Council on Foods of the A.M.A. (appendix p. 958)

While the activities indicated above were progressing, the Board was called upon innumerable times by government and other agencies during and after the war for technical advice in relation to policies and practices concerned with foods and nutrition. For example, in connection with the development of the rationing program, the Board drew up lists of priority foods based on their nutritional contribution to the national dietary. The Board was called upon during the food emergencies following the war to interpret the relation of food limitations to health, well-being, and capacity for work. Its memoranda to those concerned with allocations of food for export served as a basis for estimating needs and distributing available supplied on as equitable a basis as was possible.

It would not be fair to omit mention of the work of other committees of the Food and Nutrition Board which have been and are now quite active in the affairs of the Board. The Committee on Nutrition of Industrial Workers, formerly under the chairmanship of Dr. Boudreau and Dr. Robert S. Goodhart, issued a number of reports dealing with improvement of the status of industrial workers. The Committee on Diagnosis and Pathology of Nutritional Deficiencies, under the direction of Dr. H. D. Kruse, published the prevalence and significance of nutritional deficiencies in the United States as NRC *Bulletin* No. 109, and under the chairmanship of Dr. E. L. Severinghaus, developed a *Nutrition Program for State Health Departments*. In 1950 there was published a comprehensive book on *Clinical Nutrition* edited by Drs. Norman Jolliffe, F. F. Tisdall and P. R. Cannon. Subsequently, a Committee on Therapeutic Nutrition compiled and critically reviewed the Application of Nutritional Therapy in the Recovery from Disease, Surgery and Injury. This report emphasizing the special military application was sponsored by the Army's Office of the Surgeon General. The Committee on Fats, under the chairmanship of Dr. L. A. Maynard and Dr. H. E. Longenecker, reported on the wartime fat supplies in relation to requirements and also published its far-reaching report on margarine in 1943 as NRC *Reprint and Circular Series* No. 118. The Committee on Protein Foods issued its *Report on the Nation's Protein Supply* as NRC *Reprint and Circular Series* No. 114 in 1942 under the direction of Dr. W. C. Rose and is continuing its program under the chairmanship of Dr. Paul R. Cannon. Other publications published by the Board include a *Review of Literature on Dental Caries*, a *Study of Human Requirements for B-Complex Vitamins*, and a *Monograph on Nutrition Surveys*.

One of the major activities on the Board during the past years has been the Survey of Food and Nutrition Research currently active in academic, governmental, and industrial laboratories. These surveys have been carried out under the direction of Dr. C. G. King, Dr. W. B. Guarrant and Dr. W. C. Russell and have been supported by the QM Food and Container Institute and the USDA. The third report of this survey was published in 1954. It includes a subject listing of 4,000 research projects active in over 600 laboratories and a listing of approximately 5,000 professional personnel conducting or directing food and nutrition research in the United States. Development of this project into a continuous registry of active food and nutrition research with periodic published reports is contemplated.

One of the major activities since 1950 has been the development of the Committee on Food Protection. This committee was organized by the NRC under the Food and Nutrition Board at the request and with the financial support of food and chemical industries. The Committee has concerned itself with the development of basic principles and the evaluation procedures required to insure the safety of the food supply.

The Board has cooperated frequently with the Food and Drug Administration on requests for advice on policies which should govern the qualitative integrity of the food supply. The Board's opinions in this respect have no official authority except as they represent the sound judgment of scientists concerned only with the interests of the public.

Thus the Food and Nutrition Board has been and continues to be concerned with (1) the evaluation of human nutritional needs, (2) the adequacy of food production and distribution to meet these needs, and (3) the overall application of nutritional science to public policy and public health. Although the Board developed out of war-time expediency, its responsibilities continue to be prominent in the postwar era relative to national and international problems of food and nutrition. It has literally been an experience in social science.

2. THE AGRICULTURAL RESEARCH INSTITUTE

LeRoy Voris

Executive Secretary

On December 10, 1951, at the instigation of R. C. Newton of Swift and Company and Paul D. V. Manning of the International Minerals and Chemical Corporation, the proposal to organize the Agricultural Research Institute was presented to a gathering of representative scientists from agricultural industries and research agencies. The purpose of the proposed organization was to provide a mechanism for the collaboration of industrial, governmental, and academic scientists in promoting agricultural research and practices aimed at the best longtime utilization of the Nation's agricultural resources. The plan proposed a dual arrangement whereby the Agricultural Research Institute would be a fiscal organization of dues-paying industries having a stake in agriculture and the Agricultural Board would be a deliberative group of scientists appointed by the National Research Council. Effective liaison with the Agricultural Board was to be accomplished through technical representatives of the dues-paying members and designation of non-dues-paying member representatives from scientific societies, federal agencies, state institutions, and other associations or individuals interested in agriculture.

The plan as conceived has become a reality. Under the stimulus of the Institute, the Agricultural Board has been able to promote the activity of its current committees, to revive some of its dormant activities, and to consider the activation of new studies. The activities in the field of animal nutrition, animal health, feed composition, and seed preservation are matters of record. Activities being developed by the Agricultural Board are in the fields of animal breeding, water conservation and utilization, range and pasture management, plant diseases and pests, farm machinery and mechanization, the competition between animal and vegetable fats and oils, and cooperative research in agriculture. The implementation of these studies by the Agricultural Board was prompted by suggestions from members of the Institute. These were consolidated into specific recommendations by the Projects and Proposals Committee under the chairmanship of Roland Bethke of the Ralston-Purina Company.

In addition to providing a forum for discussion of the activities of the Agricultural Board, one of the major functions of the Agricultural Research Institute is to proffer the opportunity to review the major problem areas of agricultural research through addresses by leaders familiar with the broadest applications of agriculture to human welfare. Some of these areas are summarized in the following paragraphs.

George H. Hart, University of California, lucidly described the developmental potentials of the vast western rangelands which can be realized if proper concepts of plant and animal ecology are combined in a wise program of making the lands useful for mankind. Fire, water, and fertilizers were listed among the major factors which could contribute to this development. Dr. Hart emphasized the need for reconsideration of the current concept of carcass quality of meat animals in relation to genetics, feeding practices, and surplus fat. Infertility in cattle, hereditary defects, lethals, and dwarfism were pointed out as serious problems in animal production. Disease and pest control was discussed as a problem of wide biological implication where species competition, antibiotics, and chemicals have to be carefully adjusted to prevent detrimental imbalances.

A clear picture of the problem of utilizing the resources of fixed land areas in providing for an ever expanding population was presented by E. C. Stakman of the University of Minnesota. Land can be made more productive by provision of water, by development of plants requiring little water, by use of fertilizer, and by newer knowledge of soil microbiology and plant nutrition. The problem of plant disease and pest control was discussed with reference to disease resistance and biological or chemical control of pathogens. The maximum productive capacity of the principle agricultural crops is still an unknown quantity. The ultimate genetic capacity of the plant must be considered along with the ultimate carrying potential of the soil, and both must contend with the depredation of competitive biological systems.

J. Earl Coke, Assistant Secretary of Agriculture, presented the objectives of the reorganization of the United States Department of Agriculture, which would emphasize broadening the markets for agricultural produce at home and abroad, strengthening the research program, and decentralizing Government functions. The fact that one farm worker today provides for about fifteen people and by 1975 may have to provide for twenty-one was cited in support of pressure for cooperation in governmental and industrial research programs. The 17 per cent increase in efficiency of food production between 1940 and 1950 resulting from research was estimated to have kept retail food prices from going higher than they did by 42 per cent.

Speaking for the United States Department of Agriculture on the attainments of agricultural research, Byron Shaw noted the advances in agricultural productiveness since the establishment of the Department in 1862. He cited the cooperative development of the land-grant college system as it is working at present and recognized the need for closer cooperation with industrial research in a combined effort to meet the challenge of the future. The basic physical, biological, and economic science necessary to progressive agriculture must be continuously expanded, and concurrently the educational development of trained personnel for research and management of the resources available is essential.

James H. Hilton, President of Iowa State College, representing the land-grant colleges, defined agriculture as a basic industry responsible for supplying mankind with raw materials derived directly from the soil or indirectly by husbandry for food, clothing, and shelter. The land-grant college system in addition to contributing the necessary technology has helped to place the farmer in a respectful position with regard to investments of capital, labor, and intelligence comparable to that occupied by those in non-agricultural enterprises.

The industrial benefits resulting from research on agricultural products were discussed by Carl Miner, Director of the Miner Laboratories. He cited numerous instances of industries developed from primary agricultural produce and wastes. For example, the development of a simplified pressing machine for local manufacture of building and insulating material from corn-stalks was described as a possibility for cheap animal housing and barn insulation.

The officers elected for 1954 are: Paul D. V. Manning, President; Roland Bethke, Vice President; and Victor Conquest, Secretary.

The promise of the Institute lies in the evident willingness of its members to participate actively in making it become a cooperative endeavor for the application of objective scientific wisdom to the public welfare. Rather than a source of funds for research, the Agricultural Research Institute is a resource for the utilization of research results applicable to a beneficent agriculture.

3. FOOD AND AGRICULTURAL ORGANIZATION OF THE UNITED NATIONS (FAO)

Organized: July 1943.

Address: Viale de lle Terme di Caracalla, Rome, Italy

Objectives

To raise levels of nutrition and standards of living of the peoples, to secure improvements in the efficiency of the production and distribution of all agricultural and food products, to better the condition of rural populations, and thus to contribute to an expanding world economy.

(1) The Organization shall collect, analyze, interpret, and disseminate information relating to nutrition, food and agriculture.

(2) The Organization shall promote, and, where appropriate, shall recommend national and international action with respect to (a) scientific, technological, social and economic research relating to nutrition, food and agriculture; (b) the improvement of education and administration relating to nutrition, food and agriculture, and the spread of public knowledge of nutritional and agricultural science and practice; (c) the conservation of natural resources and the adoption of improved methods of agricultural production; (d) the improvement of the processing, marketing and distribution of food and agricultural products.

(3) It shall be the function of the Organization (a) to furnish such technical assistance as governments may request; (b) to organize, in cooperation with the governments concerned, such missions as may be needed to assist them to fulfill the obligations arising from their acceptance of the United Nations Conference on Food and Agriculture; and (c) generally to take all necessary and appropriate action to implement the purpose of the Organization.

For publications address, FAO, 1325 C St. S.W. Wash. 25, D. C.

Directory of International Scientific Organizations (2nd Ed.) Unesco (1954).

4. WORLD HEALTH ORGANIZATION (WHO)

Organized: April 1948

Address: Palais des Nations, Geneva, Switzerland

The World Health Organization (WHO) is a specialized agency of the United Nations and represents the culmination of efforts to establish a single intergovernmental health agency. As such, it inherits the functions of antecedent organizations such as the Office International d'Hygiène Publique, the Health Organization of the League of Nations, and the Health Division of UNRRA.

WHO had its origin in the proposal made at the United Nations Conference held in San Francisco in 1945 that a specialized agency be created to deal with all matters relating to health. In 1946, representatives of 61 governments met at the International Health Conference, New York, drafted and signed the WHO Constitution, and established an Interim Commission to serve until the Constitution could be ratified by 26

Member States of the United Nations. The Constitution came into force on April 7, 1948, the first World Health Assembly met in Geneva in June 1948, and on September 1, 1948, the permanent Organization was established.

The work of the Organization is carried out by three organs: the World Health Assembly, the supreme authority, to which all Member States send delegates; the Executive Board, the executive organ of the Health Assembly, consisting of 18 persons designated by as many Member States; and a Secretariat under the Director-General.

The scope of WHO's interests and activities exceeds that of any previous international health organization and includes, in addition to major projects relating to malaria, tuberculosis, venereal diseases, maternal and child health, nutrition, and environmental sanitation, special programs on public-health administration, epidemic diseases, mental health, professional and technical training, and other public-health subjects. It is also continuing work begun by earlier organizations on biological standardization, unification of pharmacopoeias, addiction-producing drugs, health statistics, international sanitary regulations, and the collection and dissemination of technical information, including epidemiological statistics.

Expert committees are an essential part of the machinery of WHO, and their function is to give technical advice to the Organization. Members of such committees are "appointed by the Director-General, in accordance with regulations established by the Executive Board." They are chosen for their "abilities and technical experience," due regard being paid to "adequate geographical distribution." Publication of reports of expert committees is authorized by the World Health Assembly or by the Executive Board.

In the field of nutrition, there is a joint FAO/WHO Expert Committee on Nutrition.

IV. RESEARCH GROUPS DEALING WITH FOODS

1. RESEARCH FOUNDATIONS NOT LIMITED TO SPECIFIC COMMODITIES

A. THE NUTRITION FOUNDATION, Inc., Chrysler Bldg., New York 17, N.Y.

Organized: 1941

Scientific Director: Dr. Charles Glen King

In December 1941, The Nutrition Foundation was incorporated by a group of leaders in the food industry who were conscious of the need for increased support of basic research and education in the science of nutrition.

There was clear recognition that the program of the new organization should be wholly in the public interest and fundamental in character, in accord with the spirit and purpose of graduate schools and medical centers in leading universities.

Both in pattern of organization and in clarity of purpose, the Foundation constituted a new type of development in the industrial and educational life of the United States and Canada. Its growth in membership and program has given evidence of the soundness of the venture.

Distinguished representatives of the public serve on the Board of Trustees, and leading scientists from universities and government agencies serve on the Advisory Committees.

Grants to universities and similar institutions in the United States and Canada are made twice each year, normally on January 1st and July 1st.

Member firms contribute to the Foundation on a five year advance basis, to provide working capital and to permit planning with a reasonable degree of continuity in support of basic research and education.

Currently research grants and publications are being carried forward in four major fields:

- (a) Research to discover the nutritional requirements
- (b) Studies of maternal and infant nutrition
- (c) Exploratory work to discover how the nutrients function in living cells, and
- (d) Direct studies of public health problems that are obviously related to nutrition, such as hardening of the arteries, hypertension, cerebral hemorrhages, diabetes, dental caries and obesity.

Most of the Foundation's grants serve a dual purpose in developing basic information in the science of nutrition and in supporting the advanced training of young scientists.

B. THE REFRIGERATION RESEARCH FOUNDATION, 200 Midland Building, Colorado Springs, Colorado

Organized: October 14, 1943

Director and Secretary: Dr. H. C. Diehl

Objectives

(1) To improve the methods of refrigeration for the better preservation of food and other commodities essential to the health and welfare of the American people.

(2) To develop and support research in the science and art of refrigeration of food and other commodities through a nationwide program of financial grants to established institutions and agencies of research.

(3) To establish fellowships in institutions and agencies of research and thereby to aid in the training of competent personnel to give activation and leadership to the refrigeration of commodities essential to the national economy.

(4) To establish in the interest of the American people a repository of scientific information relating to the refrigeration of food and other materials.

(5) To cooperate with and aid agencies of Federal and State governments, institutions of research and others in connection with their scientific and educational work involving the refrigeration of food and other products.

C. PACKAGING INSTITUTE, Inc., 342 Madison Avenue, New York 17, N.Y.

Executive Director: Dr. Laurence V. Burton

The Packaging Institute is a Technical Association, incorporated in 1939 under the laws of Delaware as a nonprofit membership association, and authorized to do business in the State of New York under Section 210 of the General Corporation Law under the name Packaging Institute, Inc. It was founded to aid its members in the solution of their technical packaging problems by mutual help.

The principal policy of the Packaging Institute is to help the producer of packaged products solve his packaging problems when these problems are technical, engineering or economic in their nature.

Thus, the activities of the Packaging Institute are chiefly concerned with protection of packaged products and the economical production of packages and packaged products.

Additional purposes of the Packaging Institute may be summarized briefly:

- (1) To provide a Forum where the complex 3-way problems arising between sup-

plier, machine builder and producer of packaged products (i.e., user of both), can be debated to the end that mutual understanding and cooperation is fostered.

(2) To develop standardized testing procedures that meet the requirements of the Institute's principal policy—service to the producer of packaged products—for testing of (a) plain and printed packaging materials; (b) fabricated and filled packages including both unit packages and shipping containers.

(3) To study the standardization of large shipping containers, e.g., drums and cans, to provide more economical utilization of transportation and materials handling equipment.

(4) To study improvements in the production of packaged products in the plant.

(5) To study possible improvements of the organization and management of the packaging function in the industries that produce packaged products.

(6) To study the educational background that leads to greatest success in the packaging function in order to encourage institutions of higher learning to adapt their curricula to the growing need for adequately trained packaging specialists.

D. QUARTERMASTER FOOD AND CONTAINER INSTITUTE FOR THE
ARMED FORCES, Chicago Quartermaster Depot, U. S. Army
1819 West Pershing Road, Chicago 9, Illinois
Organized: July 24, 1936
Technical Director: Dr. Donald K. Tressler

Objectives

Requirements for many military supplies, especially in time of war, differ markedly from standards which make similar commodities satisfactory for civilian markets in peacetime. Without research and development to meet these special military requirements, which change as tactics and logistics change, it is highly probable that adequate products would in many cases not be readily available in an emergency.

Differences between civilian and military requirements are especially clear in the case of food and containers. During wartime, food for the Armed Forces may have to undergo months or years in transit and storage under varying temperature and humidity conditions. When it is consumed—under conditions which generally are also extremely different from those under which foods going through normal supply channels are consumed—it should nevertheless be acceptable, nourishing, and in a form which does not impede military operations. Containers for military supplies must protect the commodities they hold against a far wider variety of sources of damage than are encountered in normal export shipment.

The only agency specifically charged with providing the research and development which must be performed to supply the Armed Forces of this country with foods meeting these special requirements, the Quartermaster Food and Container Institute for the Armed Forces is also responsible for providing the research and development for containers which will adequately protect all Quartermaster supplies including fuels and lubricants. The Institute is a section of the Research and Development Branch, Military Planning Division, Office of The Quartermaster General.

The Institute's mission is not only to provide the research and development for the foods and rations required by the Army, Navy and Air Force as well as for containers of all Quartermaster Supplies, but also to embody the conclusive results of this work in specifications governing procurement of these commodities. In addition, the Institute is responsible for preparing and disseminating technical information concerning these activities as well as for maintaining current plans for organizing

and expanding them in times of emergency, and for representing the Office of The Quartermaster General on military and other specifications boards and on other technical and scientific boards and commissions dealing with foods and containers and organized by various government as well as other technical groups.

E. AMERICAN INSTITUTE OF BAKING, 400 East Ontario Street, Chicago 11, Illinois

Founded in 1919

Scientific and Research Director: Dr. William B. Bradley

Objectives

It was incorporated as a not-for-profit corporation in the State of Illinois in March 1922. It has operated continuously since then in the fields of education, research, sanitation and consumer service. In October, 1950, the Institute moved into a new, modern building which was made possible by funds which had been raised by the American Bakers Foundation over a period of thirty years. Through the new facilities a widened program offers increased service to the Baking Industry and additional information to the consumer.

The Institute has its own charter and its own corporate identity, and it is directed by a Board of Directors elected from the baking and allied trades. It is financed by dues, earnings, special grants for research projects, and an annual appropriation from the Bakers of America Program for the Consumer Service Department program.

The Institute has enabled the Baking Industry to take a place of leadership among the food industries of this country. The consumer is receiving the benefits of its work in research, in sanitation and in education.

F. BOYCE THOMPSON INSTITUTE FOR PLANT RESEARCH, INC., 1086 North Broadway, Yonkers 3, New York

Organized: October 27, 1924

Director (Managing): Dr. George L. McNew

The Scope and Objectives of the Institute

It was early agreed that the Institute's contribution would be of greatest value if three main principles were carried out: (1) to attack problems in a fundamental way so that the results might contribute both to practice and to science, (2) to assemble a staff representing the many techniques required in the study of plants, and (3) to secure the best equipment possible for studying every phase of plant growth.

The Institute maintains a normal balance between fundamental research and the application of its results to the solution of practical problems. The pure research of science and the applied research of agriculture and commerce are not considered as contrasting elements in a scientist's obligation to society, but as normal extensions of each other. A spirit of cooperativeness and mutual interest in each other's projects is fostered by the staff members. The scientists enjoy freedom in seeking each other's counsel and entering into cooperative projects, unhampered by any restrictive influence of professional departments. It is recognized that few, if any, of our modern research projects can be prosecuted fully without encroaching into and drawing upon the best knowledge and techniques in different fields of scientific endeavor.

In order to provide all skills necessary for a research project, staff members trained in plant physiology, plant pathology, entomology, genetics, morphology, and chemistry have been employed. One or more members have specialized in statistical analysis to provide counsel on experimental design and interpretation of results.

2. SPECIAL RESEARCH INSTITUTIONS AFFILIATED WITH UNIVERSITIES

- A. WISCONSIN ALUMNI RESEARCH FOUNDATION, P. O. Box 2059, Madison 1, Wisconsin
Organized: 1925

Objectives

TO PROMOTE, encourage, and aid scientific investigation and research at the University of Wisconsin by the faculty, staff, alumni, and students thereof, and those associated therewith, and to provide or assist in providing the means and machinery by which their scientific discoveries, inventions, and processes may be developed, applied, and patented, and the public and commercial uses thereof determined, and by which such utilization or disposition may be made of such discoveries, inventions, and processes, and patent rights or interests therein, as may be of benefit to mankind or as may tend to stimulate and promote and provide funds for further scientific investigation and research within said University or colleges or departments thereof."

- B. ARMOUR RESEARCH FOUNDATION OF ILLINOIS INSTITUTE OF TECHNOLOGY, Technology Center, 35 West 33rd St., Chicago 16, Ill.

Founded: 1936

The Armour research staff undertakes to: (1) develop new products, processes and materials; (2) improve old ones; (3) develop natural resources; (4) adapt products for new markets; (5) find improved and cheaper operating and maintenance methods; (6) design labor-saving machinery; (7) obtain better standardization or quality-control; (8) discover substitutes for expensive or critical materials; (9) create values from waste material; (10) evaluate diversifications or expansion plans.

Basic and applied research in the food field is carried out in the Biochemistry section.

Research in the following areas is being undertaken:

Biological Evaluation Studies

Toxicity Research

Instrumentation

New Methods for Food Sterilization

Agricultural Research, Especially in Insecticides, Fungicides, Growth Factors, and Fertilizers

Industrial Microbiology

Plans for the future call for an expansion in the development and evaluation of new food products, the nutritional aspects of food processing, and all bacteriological phases of the food industry.

- C. McCOLLUM-PRATT INSTITUTE, The Johns Hopkins University, Baltimore 18, Maryland

Date of establishment: 1947

Director: Dr. William D. McElroy

Objectives

The research program of the Institute is primarily concerned with the experimental investigation of the role and significance of micronutrients in plant and animal nutrition. In addition to this, training is offered to students in the broader fields of plant and animal biochemistry, plant physiology, cell physiology, and related sciences. It is felt that on the graduate level each student is a special case, and in so far as this is

possible, the program will be kept flexible in order to meet individual needs. Through the cooperation of other science departments, certain students may work in the field of micronutrients with a different viewpoint from that emphasized by the special program of the McCollum-Pratt Institute. Normally the students will major in the Department of Biology.

D. FOOD RESEARCH INSTITUTE—THE UNIVERSITY OF CHICAGO,
Chicago 37, Illinois

Organized: 1946. Director, G. M. Dack, M. D.

The Food Research Institute co-ordinates various University investigations on basic problems of food and nutrition, and conducts research in such areas as nutritive quality of foods, preservation, spoilage and food poisoning. The Institute is a co-operative enterprise established to bring into close relationship the practical studies of the food producer, the food technologist, and the fundamental investigations of the basic scientist, and to maintain contacts with participating industrial organizations.

3. COMMODITY RESEARCH GROUPS

(A) CORN INDUSTRIES RESEARCH FOUNDATION, INC., 270 Park Avenue,
New York 17, N.Y.

Organized: February 9, 1932.

Research Director: Norman F. Kennedy

Objectives

The objects and purposes of the Corn Industries Research Foundation, Inc., as listed in its organization papers are many, for example:

"To conduct studies, engage in research and in any or all other kindred lawful activities to aid producers of . . . corn products . . .

"To foster and promote . . . the interests and general welfare of . . . corporations engaged in the production of . . . corn products . . .

"To promote the maintenance of a high standard of quality and purity of products produced by the wet-milling process;

"To develop new uses and extend existing uses . . . by creating and broadening . . . interest and knowledge of . . . products and . . . uses . . .

"To cooperate with federal, state, and municipal authorities by providing . . . information . . . pertaining to or affecting . . . the production, distribution and use of . . . corn products . . ."

(B) AMERICAN MEAT INSTITUTE FOUNDATION, 939 East 57th Street,
Chicago 37, Ill.

Director, Research and Education, Dr. H. R. Kraybill

Organization

The American Meat Institute Foundation is a non profit organization affiliated with and located at the University of Chicago. It is the outgrowth of an all-industry research program initiated by the American Meat Institute in 1924 and maintained by that organization for more than two decades. Valuable scientific contributions were made in the processing and utilization of livestock products by the Research Laboratory of the Institute. This work demonstrated the practicality of industry group research and led the Institute to make a survey of the needs for an expanded research

program and possible methods of achieving such expansion. In 1944, the Institute's Board of Directors, acting on the recommendation of the Institute staff, voted to sponsor the establishment of an independent, non-profit organization to carry out a program of research and education in livestock production, processing, and utilization. The Foundation was incorporated in 1944 and began operations on a moderate scale in 1947. In 1949, the Foundation moved into a new laboratory building on the campus of the University of Chicago. This structure is designed to meet the specific needs of the Foundation and with equipment, represents an investment of about three-quarters of a million dollars. The funds for construction and equipment of the building were contributed by several hundred meat packing companies—ranging from the smallest to the largest—and by companies in allied industries.

Purpose

The Foundation was organized to carry out a broad and comprehensive program of research and education in the field of livestock production and processing, including the utilization of livestock products. In the latter connection, technological advances resulting from intensive research in other industries, already have induced major displacements of important livestock by-products. Thus, if the livestock, meat and by-products industries are to keep abreast of the advancing times, improved or more economical processing methods, new and improved products, and new uses for such products must be developed. Such important advancements, of course, can result only from consistent and expanding attention to the types of fundamental research and technological experimentation now being conducted at the Foundation.

Affiliation with the University of Chicago

The Foundation's location in the heart of one of the great research centers of the country and its affiliation with the University of Chicago provide distinct advantages. There is opportunity for exchange of scientific information between the Foundation staff and scientists of the University, as well as with scientists with other research organizations on the campus. Some Foundation staff members hold professorial appointments in the University. A number of graduate students are doing thesis work in the Foundation's laboratories under the supervision of these Foundation scientists.

An Advisory Committee, three members of which are appointed by the University and two by the Foundation, serve to co-ordinate the programs of the two institutions in such a manner as to obtain the maximum benefit to the public and to the co-operating institutions.

(C) SUGAR RESEARCH FOUNDATION, Inc., 52 Wall Street, New York 5'
N. Y.

Organized: June 10, 1943

Executive Director: Neil Kelly

Objectives

To initiate, promote, assist, develop, maintain, conduct and carry on, directly or indirectly, investigations, studies and research relating to sugar, and any and all uses, or possible uses, of sugar, in any form whatsoever, and whether as a food or an ingredient of foods or beverages, or in industry or otherwise, including, without limiting the generality of the foregoing, the place and value of sugar in the human diet, its relationship to other foods, and its nutritional, dietary, industrial, and other

uses, purposes or effects, whether separately or as an ingredient of or in combination or conjunction with other foods or substances;

To provide, establish and maintain funds, fellowships, endowments, and other aid or facilities for such investigations, studies and research;

To obtain, collect, disseminate and distribute, by advertising and otherwise, information as to uses, purposes, utility and effects of sugar, in any form whatsoever, and whether as a food or an ingredient of foods or beverages, or in industry or otherwise.

(D) THE NATIONAL VITAMIN FOUNDATION, Inc. 15 East 58th Street,
New York 22, N. Y.

Scientific Director: Robert S. Goodhart, M.D.

The National Vitamin Foundation was organized by producers and distributors of vitamins and related products to promote and support studies of nutrition in both health and disease, particularly as they relate to vitamins, toward the end that the health and welfare of mankind may be improved through better nutrition, and to initiate and encourage research in any way relating to medicine and health. It was incorporated in the State of New York, as a non-profit membership corporation, in February 1946.

The Foundation functions (1) through the distribution of grants-in-aid to universities, colleges and other qualified research institutions and individuals for the conduct of investigative work and for the advanced training of competent investigators; (2) through sponsoring and supporting "open" symposia on current problems, research and developments in human and animal nutrition, and related medical and public health matters; and (3) through the publication and distribution, to the medical and allied professions, of the proceedings of the various symposia, and of monographs and miscellaneous publications in the fields of nutrition and metabolism.

(E) EVAPORATED MILK ASSOCIATION, 228 North La Salle Street, Chicago 1,
Illinois

Organized: February, 1923

Executive Secretary: Dr. E. H. Parfitt

Objectives

The by-laws of the Evaporated Milk Association provide that the principal activities of the Association shall be "to institute and conduct research and educational work."

Since the beginning of the Research and Educational program in 1925, more than \$5,000,000 has been spent *on research*, to determine the nutritional values of evaporated milk, and *on education*, to make the facts known to the public.

It was through research grants-in-aid made by the Association that the use of evaporated milk was demonstrated to be especially adapted for baby feeding. The result was not only that evaporated milk has been used more than any other form of cow's milk for the feeding of babies in the past 20 years, but also it has served to prove the high nutritional value and safety of evaporated milk for any milk use.

The research program has not been limited to laboratory studies and human nutrition. An extensive study of consumer attitudes was undertaken by the Association in 1950. A psychological study designed to determine the best method of changing food habits was supported at the University of Iowa in 1943.

Through a staff of home economists, nutritionists, and journalistically trained people, the Evaporated Milk Association provides editorial information to newspapers and consumer magazines, and lecture-demonstrations to schools of home economics, and other services. An experimental kitchen is used daily for the development of recipes and other food preparation suggestions.

Booklets and charts, filmstrips, motion pictures and other materials are provided as "tools" for teachers, public health and welfare workers, physicians, nurses and others who influence consumer opinion.

Lecture-demonstrations are given by a home economist before military food service school personnel for the purpose of stimulating the use of more evaporated milk and other dairy products in food prepared for the men in service.

F. NATIONAL LIVE STOCK AND MEAT BOARD, 407 So. Dearborn Street, Chicago 5, Illinois.

Organized: March 15, 1923.

Secretary-General Manager, Carl F. Neumann.

The program for meat is of broad scope in three major respects. First, it is all-inclusive in the field of research, embracing investigations to bring to light all the facts on the value of meat as a food. Second, the program is far-reaching in the field of education, with activities extending into every corner of the nation. And the third point providing evidence of the extent of endeavor is the subject matter brought into use. Every aspect of the subject of meat is covered authoritatively—meat in nutrition, meat cut identification and buying, meat carving and cutting, meat cookery, the care of meat, and the planning of menus around meat.

V. MISCELLANEOUS INFORMATION

1. A GUIDE TO THE LITERATURE ON FOOD RESEARCH AND TECHNOLOGY*

The reference resources of the food scientist increase with each passing year. Basic information on food is being reproduced in volume in numerous journals supported by the professional societies. An even greater quantity of data is being poured into the industrial and business journals. The day has passed when research on food can be done independently of industrial experience, and, in consequence, there is need for a check list that includes not only the professional journals but also the periodicals that record the technical know-how of the man in the plant. This *Guide to the Literature on Food Research and Technology* is designed as an aid to food research and development workers who are comparatively new to the field, to those who, closely confined to the more fundamental types of research, may not be aware of all the resources available to them in the semi-technical periodicals, and to workers in organizations without highly developed technical libraries who may wish to survey the sources of information in a specialized field. It is believed that this brief *Guide* is a unique effort in the cataloging of bibliographical sources for use in food investiga-

* Reproduced with permission from vol. 6, #1, 1954 Activities Report on Food and Container Research and Development for the Armed Forces.

tions. As such it is wide open for additional entries inadvertently overlooked in this initial compilation.

GENERAL SOURCES OF REFERENCE INCLUDING HANDBOOKS, PATENT RECORDS, ETC.

Agricultural Index. H. W. Wilson Co., New York.

A monthly index of periodical and pamphlet literature (including that of state agricultural experiment stations) and covering over 2,000 subjects. Includes current publications in the book field.

Bibliographical Index. H. W. Wilson Co., New York.

Initiated in 1938. Furnishes bibliographies for special fields as a service.

Bibliography of Agriculture. U. S. Department of Agriculture Library, Washington, D. C.

Initiated in 1936. Publications are available in microfilm or photoprints.

Bibliography of Technical Reports. U. S. Department of Commerce, Office of Technical Services, Washington, D. C.

Industrial Arts Index. H. D. Wilson Co., New York.

Covers business, finance, science, and technology. Founded in 1913.

International Index to Periodicals. H. W. Wilson Co., New York.

Covers all periodicals and all subjects. Issued four times a year. It provides on a cumulative basis an index (under *food*) to the literature on food on a world-wide basis.

Library of Congress Subject Catalog. Library of Congress, Washington, D. C.

An index to all copyrighted books published in the United States and includes uncopyrighted books as well as foreign publications. A primary source for bibliography in any field of inquiry.

Monthly List of the Publications of the United States Department of Agriculture. Washington, D. C.

New York Times Index. New York Times Co., New York.

An index of news items with classifications that include food and related subjects.

Publishers Weekly. R. R. Bowker Co., New York.

Contains weekly record of books published in the United States. Books referring to the various food fields are coded but the list is not sectionalized.

Quarterly Cumulative Index Medicus. 1916, American Medical Association, Chicago.

Rand McNally Commercial Atlas and Marketing Guide. 80th edition, 1949.

Contains abbreviated information on manufacturing interests and broad market potentialities of urban areas (USA).

Reader's Guide to Periodical Literature. H. W. Wilson Co., New York.

A standard source of reference. Initiated in 1900. Its predecessor, *Poole's Index*, covers 19th Century periodical literature.

Technical Book Review Index. Special Libraries Association, New York.

Abstracts reviews of technical books including those in the food field. Initiated in 1935.

Union List of Serials in Libraries of the United States and Canada. 1943, H. W. Wilson Co., New York.

This volume shows the actual periodical holdings of libraries in the United States and Canada and is the standard source for finding periodical literature in the food field (as well as all other fields).

United Nations Documents Index. United Nations, New York.

Initiated in 1950. Lists documents of the Food and Agriculture Organization; includes references in related fields.

The United States Catalog (books in print January 1, 1928). H. W. Wilson Co., New York.

The Cumulative Book Index. H. W. Wilson Co., New York.

A world list of books in the English language 1928-32; 1933-37; 1938-42; 1943-48; etc. These volumes supplement *The United States Catalog* listed above. Food references are found under food and related catchwords.

Yearbooks. United States Department of Agriculture, Washington, D. C.

Directories, Manuals, Handbooks

Annual Meat Packers Guide. National Provisioner, Inc., Chicago.

Information on products, on operating and production problems, and on machinery, equipment, supplies, ingredients in the meat packing and allied fields.

Baking Industry. Anniversary issue, 1952, Clissold Publishing Co., Chicago.

Contains the statistical history of the baking industry to 1952 together with a chronological history of the industry.

Bergey's Manual of Determinative Bacteriology. 5th edition, 1939, Williams and Wilkins Co., Baltimore, Md.

Tabulated descriptions of species of bacteria of the class *Schizomycetes* showing the morphologic, cultural, and pathogenic characters of such organisms.

Candy Industry Catalog. Published by *Candy Industry*. Don Gussow Publications, Inc., New York.

Information on supplies, food laws pertaining to candy, candy formulas, candy production, etc.

Canned Food Reference Manual. 3rd edition, 1947, American Can Company, Maywood, Ill.

A reference text on commercially canned foods. Manufacturing, technology, nutritive values of canned foods, public health aspects of canned foods, and many other topics are presented.

Canning Trade Almanac. Compiled and published each spring by the *Canning Trade*, Baltimore, Md.

Annual computation of statistics, laws, grades, and other reference data on canned food.

Food Products Directory. Published by *Western Canner and Packer*, San Francisco.

Lists food packers and distributors of the nation.

Frozen Food Processor Directory. E. W. Williams Publications, New York.

Handbook of Chemistry and Physics. 34th edition, Chemical Rubber Publishing Co., Cleveland, O.

Accurate, reliable, up-to-date information on mathematical tables, properties and physical constants of organic compounds, data on heat, electrical phenomena, light, and quantities and units. Includes conversion tables for Centigrade-Fahrenheit temperature, metric-English tables, etc.

Modern Packaging Encyclopedia. Packaging Catalog Corp., New York.

Covers new developments and solutions to packaging problems plus expositions of the characteristics and properties of the various materials and designs used in packaging food and other commodities.

Quality Control Handbook. 1951, McGraw-Hill Publishing Co., Inc., New York.

The principles and practices for achieving better quality and overcoming actual production problems in food and other forms of manufacture.

The Refrigeration Data Book, 3rd edition, 1951, The American Society of Refrigerating Engineers, New York, N. Y.

Van Nostrand's Chemical Annual. D. Van Nostrand Co., Inc., New York.

Useful data for analytical, manufacturing, and investigating chemists, chemical engineers, and students.

Other Useful Handbooks

Cereal Laboratory Methods. American Association of Cereal Chemists.

Dehydration Manual. 1943. Published by *Western Canner and Packer*, San Francisco.

Food Industries Manual. 1940, *Food Manufacture*, London.

Handbook of Colorimetry. 1936, The Technology Press, Cambridge, Mass.

Handbook of Food Manufacture. 1938, Chemical Publishing Co., New York.

Handbook of Solvents. 1953, D. Van Nostrand Co., Inc., New York.

Handbook of Sugar Analysis. 1952, J. Wiley & Sons, Inc., New York.

Manual of Dehydration. 1946, Western Regional Research Laboratory, Albany, Calif.

Methods of Vitamin Assay. 1951, Interscience Publishers, Inc., New York.

Association of Vitamin Chemists.

Official and Tentative Methods. American Oil Chemists Society.

Official and Tentative Methods of Analysis. Association of Official Agricultural Chemists.

Patent Information

Australian Official Journal of Patents. Dept. of Patents, Canberra, Australia.

Founded in 1931.

Canadian Patent Gazette. Ottawa, Canada.

Canadian Patent Office Record. Ottawa, Canada.

Volume 1 appeared in 1937. Covers patents granted, index of patents, industrial designs, and copyrights.

Official Gazette of the U. S. Patent Office. Washington, D. C.

Official Journal of Patents. Patent Office, London.

First issued in 1884.

United States Patents Quarterly. Washington, D. C.

Established in 1929. Contains a record of patents, trademarks, and copyrights.

Miscellaneous Bibliographical Resources

Literature Search on the Preservation of Food by Freezing. Parts I and II. Compiled by B. H. Weil and F. Sterne, Georgia School of Technology, Atlanta, Ga.

Merck's Annotated Bibliographies. Compiled and published by Merck & Co., Inc., Rahway, N. J.

ABSTRACTS

Abstracts of Annual Meeting Papers. American Chemical Society.

Abstracts of Annual Meeting Papers. Institute of Food Technologists, Chicago.

Normally found in the May issue of *Food Technology*.

Biological Abstracts. University of Pennsylvania, Philadelphia.

Established in 1926. Covers food and related fields but embraces, of course, the whole field of biological research as well.

British Chemical and Physiological Abstracts. Published by the British Chemical Society and the Society of the Chemical Industry, London.

Includes many studies relating to basic problems in the food field.

Chemical Abstracts. Published by the American Chemical Society, Easton, Pa.

The 47th volume was issued in 1953. Covers food chemistry in all its aspects.

Commercial Fisheries Abstracts. Fish and Wildlife Service, U. S. Department of the Interior, Washington, D. C.

Volume 1 appeared in 1944. Covers fish by species, fresh fish, preserved fish, oils, vitamins, byproducts, analytical methods, composition of fish.

Current Abstracts. Research and Development Department of General Foods Corp.

Prefaced by Library and Research Staff, Central Laboratories, Hoboken, N. J.

Initiated in 1946. Covers scientific and technical literature of food interest. Selected and abstracted by staff members of General Foods.

Dairy Science Abstracts. Commonwealth Bureau of Dairy Science, Shinfield, Reading, England.

Initiated in 1938. Compiled from world literature on dairy science—husbandry, technology, control and standards, physiology, economics, chemistry and physics.

Food Science Abstracts. Department of Scientific and Industrial Research, London.

Volume 1 appeared in 1928. Covers animal products, poultry, fish, eggs, dairy products, fats and oils, fruits, vegetables, cereals, fish, refrigeration. This is a major publication for food technologists and research workers. Its scope is virtually world-wide. The abstracts usually specify the progress made and identify the specific contribution of an investigation. Short review articles on problems of current interest appear during the year.

Horticultural Abstracts. Commonwealth Bureau of Horticulture and Plantation Crops, Kent, England.

Established in 1931. Covers the literature on crops and crop production.

Nuclear Science Abstracts. (U. S. Atomic Energy Commission.) Technical Information Branch, Oak Ridge, Tenn.

Nutrition Abstracts and Reviews. Commonwealth Bureau of Animal Nutrition, Aberdeen, Scotland.

Initiated in 1931. Covers the biological, biochemical, and physiological literature relating to animal nutrition.

Packaging Abstracts. Printing, Packaging and Allied Trades Research Association (PATRA), Surrey, England.

Initiated in 1944. Covers the chemistry of materials, design, and performance of packages and packs.

Psychological Abstracts. American Psychological Association, Inc., Washington, D. C.

Founded in 1927. Abstracts all fields of psychological literature, but is useful as a reference to sensory testing of foods and related subjects.

Refrigeration Abstracts. American Society of Refrigeration Engineers, New York.

Compiled from the technical and semitechnical literature on refrigeration. Initiated in 1946.

Squibb's Abstract Bulletin. E. R. Squibb & Sons, New York.

Statistical Abstract of the United States. U. S. Government Printing Office, Washington, D. C.

Sugar Industry Abstracts. Tate and Lyle Research Laboratories, Kent, England.

Covers the literature on the manufacture and use of sugar.

Vitamin Abstracts. Association of Vitamin Chemists, Chicago.

Initiated in 1946. Covers the literature on methods of assay, nutritional and related effects.

World Fisheries Abstracts. Food and Agriculture Organization of the United Nations, Washington, D. C.

Initiated in 1950. Reviews the technical literature on fisheries and related industries. Contains statistical information on the catches, production, distribution, and consumption of fish.

ADVANCES AND REVIEWS

Advances in Carbohydrate Chemistry. Edited by W. W. Pigman and M. L. Wolfrom. Published by Academic Press, Inc., New York.

Volume 1 was published in 1945. Each volume contains critical reviews of special topics in the broad field of carbohydrates, including sugars, polysaccharides, and glycosides. These reviews seek to integrate and evaluate and are not literature surveys in the usual sense. Biochemical, industrial, and analytical developments are included in the reviews.

Advances in Colloidal Science. Interscience Publishers, Inc., New York.

Volume 1 appeared in 1942. The review articles published in this series are of collateral interest and frequently of direct interest to food scientists since they bear on the chemical and physical phenomena associated with liquids, emulsions, suspensions such as are encountered in food products.

Advances in Electronics. Academic Press, Inc., New York.

Advances in Enzymology. Edited by F. F. Nord and C. H. Werkman. Published by Interscience Publishers, Inc., New York.

Volume 1 was published in 1941. Monographs on problems relating to enzyme behavior. Protein structure, the chemical nature of specific enzymes, the characteristics and properties of the enzymes are discussed in terms of investigative work from the beginning up to the year in which a given monograph was published.

Advances in Food Research. Edited by Emil Mrak and George F. Stewart. Published by Academic Press, Inc., New York.

This is the standard review series for the field of food research. One of its important values for the student is that it directs attention to major problems of current interest in the food field and appraises progress toward their solution. Established in 1948, these yearly volumes seek to coordinate and integrate the work done on a given phase of food research. The advantage of such critical reviews on a continuing basis is that it brings together research that has been published in various journals over a considerable time. In view of the large number of journals in the field of food science and technology the service performed by review articles is invaluable.

Advances in Protein Chemistry. Edited by M. L. Anson and John T. Edsall. Published by Academic Press, Inc., New York.

Volume 1 was published in 1944. Critical evaluations of the advances in protein chemistry. Proteins as they occur in nature, protein nutrition, estimation of amino acids, antibody formation and many other aspects of the work being done on proteins are treated.

Annual Review of Biochemistry. Edited by J. M. Luck, Stanford University Press, Stanford, Calif.

Volume 1 appeared in 1932. Reviews of current developments in 25 to 30 fields of major interest. The biochemistry of fats, oils, proteins, carbohydrates, are treated. The bacteria, fungi, enzymes and numerous other topics related directly or indirectly to food are discussed in terms of annual advances.

Annual Review of Microbiology. Edited by Charles E. Clifton. Published by Annual Reviews, Inc., Stanford, Calif.

Volume 1 appeared in 1947. The reviews concern many other problems than those in the food field but when a topic of food interest is reviewed a thorough background of prior and current research is furnished.

Annual Review of Plant Physiology. Stanford University Press, Stanford, Calif.

Bacteriological Reviews. Published in Baltimore, Md., by the Society of American Bacteriologists.

Initiated in 1936. Authoritative, critical surveys of subjects and problems in the fields of microbiology.

Borden's Review of Nutrition Research. Borden Co., New York.

Founded in 1940. Contains abstracts, bibliography, and reviews of nutritional problems of current interest.

Chemical Reviews. Published in Baltimore, Md., by the American Chemical Society.

Authoritative critical reviews and summaries of current research in theoretical chemistry.

Merck's Vitamin Reviews. Merck & Co., Inc., Rahway, N. J.

Nutrition Reviews. Nutrition Foundation, Inc., New York.

Initiated in 1943. Covers the fields of nutrition and dietetics.

Review of Applied Entomology. Commonwealth Institute of Entomology, London.

Founded in 1913. This review includes articles of collateral interest in food research.

Review of Applied Mycology. Commonwealth Mycological Institute, Surrey, England.

Founded in 1922. Articles of collateral interest in food research appear in this British review.

Vitamins and Hormones. Edited by Robert S. Harris and Kenneth V. Thimann. Published by Academic Press, Inc., New York.

The first volume appeared in 1943. Appraisals of contributions in the chemistry and physiology of vitamins and hormones; their sources and methods of assay are also included in the reviews. All active research in the vitamin and hormone field is covered though not in the volume for any one year.

SCIENTIFIC AND INDUSTRIAL JOURNALS DEVOTED TO FOODS IN GENERAL

Technical

Agricultural and Food Chemistry. Published by the American Chemical Society.

Volume 1 appeared in 1953. Covers the chemistry of foods, pesticides, and related subjects. Contains food field news and editorials.

Applied Microbiology. Published by the Society of American Bacteriologists at Baltimore, Md.

Articles are oriented toward the application of microbiological sciences to the fields of industry, foods, sanitation, and other areas involving the use or control of microorganisms.

Archives of Biochemistry and Biophysics. Published in Baltimore, Md. Edited by a committee of scientists in these two fields.

Initial volume appeared in 1908. Articles are on chemical and physical problems including those related to the biochemistry of foods.

Biochemical Journal. Cambridge University Press, London. A. Neuberger, chairman of the editorial board.

Volume 1 appeared in 1899. Covers biochemical problems of current interest.

Biochimica et Biophysica Acta. Elsevier Publishing Co., New York. Edited by an editorial board composed of leading scientists in these fields.

Volume 1 appeared in 1942. An international monthly devoted to biochemical and biophysical studies, chiefly original studies on metabolism and nutrition.

British Food Journal and Hygienic Review. British Analytical Control, London.

First appeared in 1899. Subject matter range includes articles on sanitation.

British Journal of Nutrition. Published by Cambridge University Press for the Nutrition Society, London. S. K. Kon, chairman of the editorial board.

Volume 1 was issued in 1947. Original work in all branches of nutrition.

Canadian Journal of Research. Section F: Technology. National Research Council, Ottawa, Canada.

Volume 1 appeared in 1929. Covers chemical science and various technologies involving chemistry, including food.

Cereal Chemistry. Published by the American Association of Cereal Chemists, St. Paul, Minn.

Volume 1 was issued in 1924. Covers the chemical phases of the milling and baking industries. Problems relating to the raw materials, to the various flours, and to the non-cereal ingredients used in the manufacture of cereal products are reported.

Chemie et Industrie. Les Presses Documentaires, Paris.

Established in 1917. Coverage includes highly technical articles on basic subjects as well as industrial applications, patents, statistics of interest to food scientists.

Chemische Zentralblatt. Akademie-Verlag, Berlin.

Chemistry and Industry. Society of Chemical Industry, London.

Founded in 1881. This journal includes articles of direct interest to food technologists and scientists as well as highly technical exposition of basic investigations.

Food, Drug, and Cosmetic Law Journal. Commerce Clearing House, Inc., and Food Law Institute, Inc., Chicago.

Volume 1 appeared in 1945. Records progress of the law in the field of foods, drugs and cosmetics. Furnishes forum for discussion of such laws.

Food Research. Published by the Institute of Food Technologists at Champaign, Ill.

Volume 1 appeared in 1936. Fundamental investigations in food chemistry, bacteriology, nutrition, etc., are reported in this journal.

Food Technology. Published by the Institute of Food Technologists at Champaign, Ill.

Vol. 1 was issued in 1946. The subject matter includes contributions relating to bacteriology of foods, food problems of a chemical nature, food evaluation by sensory tests, food engineering, and to a limited degree food economics. All articles are slanted toward production problems. Editorials, news of the regional sections, and news of the food field are included in each issue.

Food Technology in Australia. Published by the Council of Australian Food Technology Associations at Sydney, Australia.

Volume 1 appeared in 1948. Contains technical articles and news of the food industries in Australia.

Journal of the American Dietetic Association. Published by the American Dietetic Association at Chicago.

Volume 1 appeared in 1925. Discusses administrative problems, therapeutic problems, normal diets, corrective diets, diet systems.

Journal of the American Oil Chemists' Society. Published by the American Oil Chemists' Society at Champaign, Ill.

Scientific articles relating to the composition, sources, utilization, and related factors concerning vegetable oils, mineral oils, and oils of animal origin.

Journal of the Association of Official Agricultural Chemists. Published by the Association of Official Agricultural Chemists at Washington, D. C.

Volume 1 was issued in 1915. The purpose of the journal is to aid in standardizing methods of analysis and of research developed for use in the sciences of food and agriculture. References to a standard method usually eliminates the need to describe it in a technical paper.

Journal of Bacteriology. Published by the Society of American Bacteriologists at Baltimore, Md.

Founded in 1916. Contributions to the field of bacteriology including numerous papers relating to the bacteriology of foods. Bacteriological studies on foods, of

course, appear in numerous other journals and it should be pointed out that this is the journal for the more fundamental type of study.

Journal of Biological Chemistry. Published by the American Society of Biological Chemists at Baltimore, Md.

First issued in 1905. This journal contains articles on food chemistry and nutrition; of interest to food research workers also are articles relating to the medical aspects of food.

Journal of Colloid Science. Academic Press, Inc., New York.

First issued in 1946. Articles relating to the physical composition and properties of organic substances and compounds of interest to food scientists.

Journal of Home Economics. Published by the American Home Economics Association at Washington, D. C.

First issued in 1908. Covers news of the association, research problems, and general articles relating to home economics.

Journal of Organic Chemistry. Williams and Wilkins Co., Baltimore, Md.

Originated in 1936. Articles related to food appear in almost every issue; the references to food are often indirect.

Journal of the Science of Food and Agriculture. Published by the Society of Chemical Industry, London.

Volume 1 appeared in 1949. Articles report original investigations in food and agriculture; content and style are technical.

Ministry of Food Bulletin. Published for the Ministry of Food by Her Majesty's Stationery Office, London.

Contains news, some technical articles, and official Ministry of Food announcements relating to the British food industries.

Industrial

British Packer. Whitaker and Cam, Ltd., London.

Initiated in 1946. Subject matter includes processing, packaging, container design, transport, and distribution. Semitechnical style and subject matter.

Canadian Food Industries and Canadian Food Packer. Federal Publications, Ltd., Gardenvale, Quebec, Canada.

Volume 1 appeared in 1930. Technical and news articles relating to Canadian food industry.

Canner. Canner Publishing Co., Chicago. Semi-technical and general articles for food processors.

Canning Trade. Published at Baltimore, Md.

Volume 1 appeared in 1878. Business aspects of the canning trade.

Food and Cookery Review. Universal Cookery and Food Association, London.

Founded in 1897. Contains articles of semi-technical nature and book reviews in the general field of food and food preparation.

Food Engineering (formerly *Food Industries*). McGraw-Hill Publishing Co., Inc., New York.

Founded in 1928. Contains technical articles on quality control, equipment, new manufacturing techniques, new foods and articles of interest to management from a cost point of view.

Food Field Reporter. Topics Publishing Co., Inc., New York.

First appeared in 1933. Covers news of the food and grocery industries.

Food Manufacture. Leonard Hill, Ltd., London.

Volume 1 appeared in 1925. Covers problems of the British food industry and news thereof.

Food Packer. Vance Publishing Corp., Chicago.

First issued in 1920. Devoted to problems of the production line; canning, preserving, glass packaging, and freezing. News coverage in relation to these industries.

Food Preservation Quarterly. Commonwealth Scientific and Industrial Research Organization. Homebush, Australia.

Volume 1 appeared in 1940. Contains scientific and technical information on food preservation, processing, and transportation.

Food Processing. Putman Publishing Co., Chicago.

First issued in 1940. Processing developments and quality control are featured.

Food; Processing, Packing, Marketing. Nema Press, Ltd., London.

Volume 1 was printed in 1931. The coverage is complete with respect to commodities and the treatment ranges from semi-technical to technical with considerable emphasis on production figures, food legislation, and similar topics.

Frosted Food Field. Frosted Food Field, Inc., Wallington, N. J.

The news of the frozen food industry including warehousing and transportation aspects.

Ice and Refrigeration. Nickerson and Collins Co., Chicago.

Feature articles relating to the ice industry and refrigerated warehousing. Occasional technical articles.

Modern Packaging. Modern Packaging Corp., New York.

First issued in 1927. Contains technical information and also news of the industry including statistical records.

Modern Refrigeration. Empire House, London.

First issued in 1898. Technical information plus information on patents and industrial techniques.

Quick Frozen Foods and the Locker Plant. E. W. Williams Publications, Inc., New York.

Established in 1938. Processing and distributing information; contains also market, patent, and statistical information relating to frozen foods.

Western Canner and Packer. Miller Freeman Publications, San Francisco.

Technical and Industrial Journals Devoted to Specific Commodity Groups

Beverages

Technical

Journal of the Institute of Brewing. Cambridge, England.

Volume 1 appeared in 1895. Contains technical articles including nutritional aspects of brewed products.

Industrial

American Brewer. American Brewer Publishing Corp., New York.

First issued in 1867. Some technical articles but mainly industry and statistical information.

Brewer's Journal. Gibson Publishing Co., Chicago.

Founded in 1876. Industry news and technical articles.

Coffee and Tea Industries and the Flavor Field. Spice Mill Publishing Co., New York.

First appeared in 1878. Contains technical information but largely devoted to market and statistical information.

Flüssiges Obst. Frankfurt, Germany.

Founded in 1930. Contains articles on fruit juices, chiefly of interest to the European industry.

Harper's Wine and Spirit Gazette. Harper and Co., London.

Founded in 1880. Industry news, abstracts of technical articles of production or distribution interest.

Tea and Coffee Trade Journal. Tea and Coffee Trade Journal Co., New York.

Founded in 1901. Industry news, markets, statistics.

Cereal and Baked Products

Technical

Cereal Chemistry. Published by the American Association of Cereal Chemistry, Minneapolis, Minn.

Original scientific papers dealing with raw materials, processes or products of the cereal industries, analytical procedures, technological tests, fundamental research. This journal is indispensable to the research workers in the field of cereal and baked products.

Industrial

American Baker. Miller Publishing Co., Minneapolis, Minn.

First volume appeared in 1924. Industry news and statistics.

Baker's Digest. Siebel Publishing Co., Chicago.

Founded in 1926. Technical digests of baking practices, innovations, and equipment advances.

Baker's Review. New York.

News of the baking industry, including personnel notes, association news, new equipment. Founded in 1898.

Baker's Weekly. American Trade Publishing Co., New York.

Articles and news of interest to sales and management forces.

Baking Industry and Baker's Helper. Clissold Publishing Co., Chicago.

Covers technological progress in the baking field; includes news articles.

Macaroni Journal. Published by the National Macaroni Manufacturers Association, Braidwood, Ill.

Volume 1 appeared in 1919. Devoted to news of the industry but also discusses technical problems of interest in manufacturing.

Modern Miller. Modern Miller Co., Chicago.

First issued in 1878. Industry news and statistics.

Rice Journal. New Orleans.

First issued in 1898. Statistical information and technical studies.

Soybean Digest. American Soybean Association, Hudson, Iowa.

First appeared in 1939. Industry information and some technical articles.

Confections

Industrial

Candy Industry. Don Gussow Publications, Inc., New York.

First appeared in 1944. Market and industry news, patent information, legislation affecting candy are the fields of interest.

Confectioner. Alva H. Cook, Milwaukee.

Founded in 1916. Manufacturing and retail trade information.

Confectioner's Journal. Confectioner's Journal Publishing Co., Philadelphia.

Volume 1 appeared in 1874. Manufacturing, management, and merchandizing methods.

Confectionery Production. Specialized Publications, Surrey, England.

Founded in 1935. Contains both technical and practical information in the field of confectionery manufacture.

International Confectioner. International Confectioner, Inc., New York.

First issued in 1892. Technical and trade information.

Manufacturing Confectioner. Manufacturing Confectioner Publishing Co., Chicago.

Volume 1 appeared in 1921. Management, production, equipment news.

Sugar Journal. New Orleans.

Founded in 1898. Scientific articles relating to sugar. The relationship of these articles to confectionery interests is not direct but provides technical background for the confectionery technologist.

Dairy Products

Technical

Journal of Dairy Research. Cambridge University Press, London.

Founded in 1921. Articles are scientific in nature.

Journal of Dairy Science. Published by the American Dairy Science Association at Champaign, Ill.

Established in 1917. Publishes articles of research interest.

Journal of Milk and Food Technology. International Association of Milk and Food Sanitarians, Albany, N. Y.

Founded in 1937. Technical reports relating to sanitation.

Journal of the Society of Dairy Technology. Published by the Society of Dairy Technology, London.

First published in 1947. Discusses problems of the dairy industry in semi-technical terms.

Industrial

American Butter and Cheese Review. Urner-Barry Co., New York.

Established in 1939. Publishes an annual volume which contains a directory of the industry and other reference material. Regular issues are devoted to news, market data, and statistical information.

American Milk Review. Urner-Barry Co., New York.

Founded in 1939. Market news, statistical reports, technical and semi-technical discussions of milk problems and product development.

Butter, Cheese, and Milk Products Journal. Olsen Publishing Co., Milwaukee.

Founded in 1910. Contains news of interest to manufacturers and technologists in the product fields listed; namely, butter, cheese, sweet cream, whole, dry, evaporated, and condensed milks; includes technical articles on manufacturing methods.

Dairy Industries. Dairy Industries, Ltd., London.

Volume 1 appeared in 1935. Technical articles and news; includes ice cream manufacture.

Dairy Record. Dairy Record Publishing Co., Inc., St. Paul, Minn.

News weekly of the dairy industry. Production, markets, controls, etc.

Ice Cream Review. Olsen Publishing Co., Milwaukee.

Feature articles, convention news; maintains a technology department. Established in 1917.

Ice Cream Trade Journal. Trade Paper Division of Reuben H. Donnelly Corp., New York.

Established in 1905. Deals with manufacturing problems, sales and management interests, and includes news of the industry.

Milk Industry. National Dairymen's Association, Inc., London.

Semi-technical and technical articles relating to the production, processing, and distribution of milk.

Milk Plant Monthly. National Milk Publishing Co., Inc., Chicago.

Volume 1 appeared in 1911. New techniques, sales promotion, management problems.

Fish

Technical

Allgemeine Fischerei-Zeitung; Fachblatt für sämtliche Zweige der Binnensfischerei und Fischzucht. Munich, Germany.

Volume 1 appeared in 1876. Covers fishery products, production, statistics, but also publishes technical articles.

Australian Journal of Marine and Fresh Water Research. Commonwealth Scientific and Industrial Research Organization, Melbourne, Australia.

First issued in 1949. Publishes studies on products and production practice; technical treatment predominates.

Journal of the Fisheries Research Board of Canada. Published at the University of Toronto.

Technical articles relating to fisheries and fishery products. First issued in 1943.

Industrial

Atlantic Fisherman. Atlantic Fisherman, Inc., Goffstown, N. H.

Founded in 1920. Covers market news.

Canadian Fisherman. National Business Publications, Ltd., Gardenvale, Quebec.

Founded in 1914. Contains news of the industry as well as notes and articles of a technical nature.

Fishing Gazette. Fishing Gazette Publishing Corp., New York.

Volume 1 appeared in 1884. Production, distribution, and general news relating to fisheries and production. Publisher's *Annual Review* number is devoted to a survey of the year's industrial progress.

Pacific Fisherman. Miller-Freeman Publications, Inc., Seattle, Wash.

Initiated in 1903. Covers news, West Coast industry problems, and the equipment fields.

Pan-American Fisherman. San Diego, Calif.

Founded in 1947. Coverage is almost exclusively the industry news of Pan-American fisheries.

Southern Fisherman. H. L. Peace Publications, New Orleans.

The first issue appeared in 1941. Covers all phases of the southern fishing industry.

Fruit

Technical

American Fruit Grower. American Fruit Growers Publishing Co., Cleveland, O.

Established in 1889. Contains technical and semi-technical articles relating to growing practices. News of production interest, markets, statistics is included.

Industrial

Citrus Industry. Bartow, Fla.

Founded in 1920. Contains some technical information along with industry news.
Eastern Fruit Grower. Ralph N. Dorsey, Boyce, Va.

Established in 1938. Covers apple and peach industry. Technical information of interest to these industries.

Fruit Products Journal and American Food Manufacturer. Avi Publishing Co., New York.

Founded in 1921. Technical articles and industry news.

Meat**Technical**

American Journal of Veterinary Research. Published by the Veterinary Medicine Association at Champaign, Ill.

Established in 1940. Includes articles related to meat inspection.

Journal of Animal Science. American Society of Animal Production. Published at Banta Publishing Co., Menasha, Wis.

Technical articles on chemical, histological, and nutritional aspects of animal science. Founded in 1942.

Industrial

Meat. Meat, Inc., Chicago.

Deals with operating and management problems of the meat packer. Volume 1 appeared in 1934.

National Provisioner. National Provisioner, Inc., Chicago.

Founded in 1889. Market news, statistics, patent literature; semi-technical articles on manufacturing problems.

Poultry**Technical**

American Egg and Poultry Review. Urner-Barry Co., New York.

Volume 1 appeared in 1940. Contains technical information as well as market news and statistics.

Canadian Poultry Review. Donovan Publications, Toronto.

Founded in 1877. Technical in nature but news of the industry is included.

Poultry Science. Poultry Science Association, Ohio State University, Columbus.

First issued in 1921. Technical studies relating to poultry.

U. S. Egg and Poultry Magazine. Institute of American Poultry Industries, Chicago.

Founded in 1895. Technical treatment of poultry problems of industrial concern.

World's Poultry Science Journal. World's Poultry Science Association, Cornell University, Ithaca, N. Y.

Founded in 1945. Technical discussions of poultry problems; international coverage.

Industrial

American Poultry Journal. Chicago.

Founded in 1874. Contains market news, statistical reports, some technical materials, usually with the grower's interests in mind

Poultry Tribune. J. W. Watt, Mount Morris, Ill.

Volume 1 appeared in 1895. Market and industry news.

Vegetables

Industrial

Packer. Packer Publishing Corp., New York.

Founded in 1901. Growing, packing, shipping, and distribution information relating to fresh fruits and vegetables.

Potato Chipper. National Potato Chip Institute, Inc., Cleveland, O.

Founded in 1941. Articles relate to the industry—markets, statistics, equipment

BASIC BOOKS

For the Over-All View

Jacobs, Morris B. *The Chemistry and Technology of Food and Food Products*. Two vols., 1944, Interscience Publishers, Inc., New York.

This monumental work is a standard reference for all phases of food research and technology.

Jensen, Lloyd B. *Man's Foods*. Nutrition and environments in food gathering times and food producing times. 1953, The Garrard Press, Champaign, Ill.

The fascinating story of food, beginning with earliest times. Integrates food production with the foundation and progress of civilization.

Parker, Milton E. *Food Engineering*. Vol. I, 1952, Reinhold Publishing Co., New York.

Prescott, S. C., and Proctor, B. E. *Food Technology*. 1937, McGraw-Hill Publishing Co., Inc., New York.

A leading textbook and a prime source for orientation in the field.

Sherman, H. C. *Chemistry of Food and Nutrition*. 1937, Macmillan Publishing Co., New York.

A standard reference for this subject matter.

Winton, A. L., and Winton, K. *The Structure and Composition of Foods*. 1922, J. Wiley & Sons, Inc., New York.

For Insight Into the Various Constituents of Foods and Their Behavior

Ball, C. O. *Mathematical Solution of Problems on Thermal Processing of Canned Foods*. University of California, Berkeley. Publications on Public Health, 1, 15 (1928).

A classic reference for heat processing studies.

Bloor, W. R. *Biochemistry of the Fatty Acids and Their Compounds, the Lipids*. 1943, Reinhold Publishing Co., New York.

Cohn, E. J., and Edsall, J. T. *Proteins, Amino Acids and Peptides*, 1942, Reinhold Publishing Co., New York.

Gilman, Henry. *Organic Chemistry*. 1943, J. Wiley & Sons, Inc., New York.

The definitive treatment of this vast subject.

Kertesz, Z. I. *The Pectic Substances*. 1951, Interscience Publishers, Inc., New York, N. Y.

Rosenberg, H. R. *Chemistry and Physiology of the Vitamins*. 1942, Interscience Publishers, Inc., New York.

Sumner, J. B., and Myrback, K. *The Enzymes*. 1950, Academic Press, Inc., New York.
Tauber, H. *Enzyme Chemistry*. 1937, J. Wiley & Sons, Inc., New York.

For the Special Commodity Fields

Amerine, M. A., and Joslyn, M. A. *The Commercial Production of Table Wines*. 1940, University of California.
Bridges, M. A., and Mattice, M. R. *Food and Beverage Analysis*. Lea and Feiberger, Philadelphia.
Jensen, L. B. *Microbiology of Meats*. Revised, 1954, The Garrard Press, Champaign, Ill.
Kent-Jones, D. W., and Amos, A. J. *Modern Cereal Chemistry*. 1947, Liverpool, England.
Lamper, M. C. *Milk and Dairy Products*. 1947, Chemical Publishing Co., New York.
Morgan, R. Harold. *Beverage Manufacture*. 1938, London.
Tressler, D. K. *Marine Products of Commerce*, 2nd edition, 1951, Reinhold Publishing Co., New York.
Tressler, D. K., and Evers, C. F. *The Freezing Preservation of Foods*. Reinhold Publishing Co., New York.
Tressler, D. K., and Joslyn, M. A. *Fruit and Vegetable Juice Production*. 1954, Avi Publishing Co., New York.

For Important Collateral Interests in Food Research

Dack, G. M. *Food Poisoning*. Revised edition, 1949, The University of Chicago Press, Chicago.
McCullough, E. C. *Disinfection and Sterilization*. 1936, Lea and Feiberger, Philadelphia.
Tanner, F. W. *Food Borne Infections and Intoxicants*. Revised edition, 1952, The Garrard Press, Champaign, Ill.

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2. FOOD PLANT SANITATION

Modern food processing plant operation requires constant surveillance of the sanitary conditions under which raw materials are stored, equipment operated, and finished products warehoused. This has developed for a number of reasons:

1. Consumer demand that "good housekeeping practices be employed in the handling and processing of foods."
2. Increasing recognition by the processor that such practices develop consumer confidence in his products, and more uniform quality; consequently higher sales volume.
3. The positive requirements of the Food, Drug, and Cosmetic Act dealing with adulteration of foods. (See 402, a(3) filthy, putrid or decomposed substance.)

4. The development of new analytical and other test procedures to detect contamination of foods.
5. The development and use of modern inspection techniques by Federal, State and local Food and Sanitation Inspectors.

In actual practice the number of special factors requiring attention is numerous and each necessitates a complete and working knowledge of the basic principles and practices pertinent to such conditions. Situations requiring special consideration are such items as the sanitary aspects of buildings and food handling equipment, water supply, waste disposal and utilization, pest control, insect control, rodent control, germicides, detergents, sanitizers, packaging operations, packaging materials, training of personnel in sanitary practices, selection of proper material for piping, conveyor belts and other pieces of equipment, and sterilizing facilities for equipment.

In the development of a comprehensive and effective program of sanitation, there must be effective, over-all supervision in the person of a trained Sanitation Engineer whose training and experience have been developed in the food field.

The importance of food plant sanitation in our modern food technology is now fully recognized. Extensive articles on various phases of this broad field are currently presented in today's scientific food literature. National organizations of specialists in this field also attest to the recognition of food plant sanitation as a highly important factor in food processing operations. The Association of Food Industry Sanitarians, Inc., in cooperation with The National Cannery Association has published a valuable and thorough book on sanitation for the Food Preservation Industries (McGraw-Hill Book Co., Inc., 1952). In addition, attention is directed to "Food Plant Sanitation" by M. E. Parker (McGraw-Hill Co., Inc., 1948), and the following texts which will be found useful:

"Hygienic Fundamentals of Food Handling," Thom and Hunter, Williams and Wilkins, 1924.

"Food-Borne Infections and Intoxications," Tanner, Second Edition, 1953.

"The Microbiology of Foods," F. W. Tanner, Second Edition, 1944.

"A Laboratory Manual for the Canning Industry," National Cannery Association, 1954.

"Fruit and Vegetable Juice Production," Tressler and Joslyn, Avi Publishing Co., Inc., 1954.

Jensen's "Microbiology of Meats"—Third Edition, 1954.

See also Chapter 24—Disposal of Food Plant Wastes—page 751.

All of these contribute materially to the overall concept of adequate and modern food plant sanitation.

Numerous scientific and trade publications currently also carry articles dealing with the advances in food plant sanitation both from the standpoint of new agents as well as new techniques.

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